DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MODELING AND SOLVING ASSEMBLY LINE DESIGN PROBLEMS BY CONSIDERING HUMAN FACTORS WITH AN APPLICATION

by
Nur AKTAŞ

February, 2015
İZMİR

MODELING AND SOLVING ASSEMBLY LINE DESIGN PROBLEMS BY CONSIDERING HUMAN FACTORS WITH AN APPLICATION

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of Science
in Industrial Engineering, Industrial Engineering Program

by
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February, 2015
İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"MODELING AND SOLVING ASSEMBLY LINE DESIGN PROBLEMS BY CONSIDERING HUMAN FACTORS WITH AN APPLICATION"** completed by **NUR AKTAŞ** under supervision of **PROF.DR. ADİL BAYKASOĞLU** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ACKNOWLEDGEMENTS

First of all, I would like to give special thanks to my advisor Prof. Dr. Adil BAYKASOĞLU for his patience, continuing support, suggestions and invaluable advice throughout the progress of this master thesis. His belief about this project always encourage me on studying.

I would like to express my great thanks especially to my mother and family. They always believe, confidence and encourage me in my whole life.

In addition, I would like to send special thanks to my smart and well-behaved son Yağız and husband Serhat because of their love, whenever I need, and listening to my complaints during this period.

Finally, the present study is supported by Ministry of Science, Industry and Technology of Turkey, San-Tez, Project Number: 1512.STZ.2012-2. I would like to present thanks everyone who is in SAN-TEZ team to their helps for completing this thesis.

Nur AKTAŞ

MODELING AND SOLVING ASSEMBLY LINE DESIGN PROBLEMS BY CONSIDERING HUMAN FACTORS WITH AN APPLICATION

ABSTRACT

Automobile cable network(harness) production area is divided into two groups as sub assembly and assembly line. Balancingprocess is generally consisted of sub assembly, assembly line, enrichment assembly andelectrical test.In this thesis, harness assebly line balancing problem is studied. While assembly line balancing is done at the same time pay attention that the assebly stations are ergonomically designed and the similiar tasks are grouped together. The goal is detected the acceptable ergonomic risk levels and made the balancing by considering ergonomic constraints. Thisstudy is a part of a San-Tez project that has a1512.STZ.2012-2 project number which is supported by Ministry of Science, Industry and Technology of Turkey.

Keywords: Ergonomic risk factors, assembly lines, assembly line balancing, harness, OCRA index

MONTAJ HATTI TASARIM PROBLEMLERİNİN İNSAN FAKTÖRLERİ DİKKATE ALINARAK MODELLENMESİ ÇÖZÜMÜ VE BİR UYGULAMA ÖRNEĞİ

ÖZ

Otomobil kablo ağıüretim alanı, alt montaj ve montaj hattı olarak iki gruba ayrılır. Montaj süreci genel olarak alt montaj, montaj hattı, zenginleştiricilerin uygulanması ve elektriksel test aşamalarından oluşmaktadır. Bu çalışmada kablo ağıüretiminde montaj hattı dengelemeproblemi açıklanmaktadır. Hat dengelemesi yaparken aynı zamandamontaj istasyonlarının ergonomik olarak tasarlanabilmesine, birbirine benzer işlerin gruplanmasına dikkat edilmiştir. Amaç işlerin kabul edilebilir ergonomik risk seviyelerini tespit etmek ve ergonomik kısıtları da dikkate alarak dengelemenin yapılamasıdır. Bu tez çalışması Bilim, Sanayi ve Teknoloji Bakanlığı tarafından desteklenen 1512.STZ.2012-2 numaralı bir San-Tez projesinin parçasıdır.

Anahtar Kelimeler: Ergonomik risk faktörleri, montaj hatları, montaj hattı dengeleme, kablo ağı, OCRA indeksi

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CHAPTER ONE
INTRODUCTION

1.1 Objectives and Motivations

Nowadays, under the conditions of tough competition in the evolving and changing industry businesses are recognized the importance of an efficient production system.The way to reduce the production costs and respond to the customer demand in time is passed from the standard production system in fictionalized assembly lines.

Assembly lines were first introduced by Henry Ford in 1913. He was the first to introduce a moving belt in a factory. Before the moving belt, workers were able to build one piece of an item at a time instead of an item at a time. This changed type of manufacturing system and reduced the cost of production. Thus assembly lines are so important for the efficiency of the work system.

Setting up or reconstruction of an assembly line isan expensive investment. Therefore, design of efficient assembly lines at the beginning recieved much attention. A well-known assembly design problem is assembly line balancing problem(ALBP). An assembly line is a flow-oriented production system where the productive units performing the operations, referred to as workstations, are aligned in a serial manner. Tasks require certain time to be processedand they are related with the existing technological constraints.

Manufacturing a product on an assembly line requires partitioning the total amount of work into a set of elementary operations named tasks. Performing a task j takes a task time t_j and requires certain equipment of machines and/or skills of workers. Due to technological and organizational conditions, precedence constraints between the tasks have to be determined. These elements can be summarized and visualized by a precedence graph. It contains a node for each task, node weights are the task times and arcs express precedence constraints.Any type of ALBP aims at finding a feasible line balance, i.e., an assignment of each task to exactly one station such that the precedence constraints and possibly further restrictions are fulfilled.

The role of assembly lines has been changing through time. Assembly lines were firstly created to produce a low variety of products in high volumes. They allow low production costs, reduced cycle times and accurate quality levels. These are important advantages from which companies can benefit if they want to be competitive.

Companies can produce several models in an assembly line. The models have a number of features, and the customer can choose a model based on their desires and financial capability. Different features mean that different additional parts must be added on the basic model. Due to high cost of building and maintaining an assembly line, design is getting much more importance to be modeled at the beginning of the production time.

While designing an assembly line both the technical constraints about the requirements and the ergonomic constraints that affect the labor performance are considered to bring a realistic approach to the problem and increase the feasibility of the solution.

The design of effective workplaces must take into consideration both the study and analysis of working methods(by means of work measurement) and the ergonomic risks (by means of specific ergonomic standards). The design of an assembly line and its workstations is characterized by some critical factors such as the work assignment, the line balancing and the ergonomic optimization of each single work station. Such aspects become more and more important during the design phase, when the assembly line is not in existence, because the designer could diagnose and resolve problems gaining insight about the system behaviour (Longo et al., 2006).

With regard to ergonomic analysis, usually the objective is to evaluate potential hazard, musculoskeletal disorders, risks related to excessive weights as well as specific risk factors concerning lifting tasks or energy expenditure working operation being performed.

In this study a harness assembly line balancing problem is studied which is an one-sided, closed line that the harness assembly process continued on the returned boards. The returned board assembly line corresponds the straight line. The harness production is an extremely labour-intensive and tedious process. So while balancing the assembly line concidering ergonomic risk factors are crucial because of the importance of human labor. The aim of the study is minimizing the number of stations not the cycle time. The assembly line balancing problem is defined in detail in Section 4.

This thesis is a part of a study that is supported by Ministry of Science, Industry and Technology of Turkey, San-Tez, Project Number: 1512.STZ.2012-2. The title of the study is “Development of a systematic that computer-aided assembly station design the production of automobile cable network effectively, which is taking into account of the ergonomic risk factors”.This whole study is focused on the design problem of the assembly lines and model the system by considering the ergonomy that is especially included the evaluation of the human factors in today’s working conditions. It is believed that the study will get attention to ergonomic risk factors and be a good application.

1.2 Outline of the Thesis

The remaining of this thesis is organized as follows: Section 2 describes assembly line balancing problem and characterizes the special assembly line balancing problem of the study.Section 3 describes theliterature review that are divided into 4 group: ergonomics science, ergonomics business systems, effects of ergonomic conditions in manufacturing environment and ergonomic risk factors in assembly line balancing problem.

Section4 presentsthe harness production systemand especiallyharness production assembly line balancing problem.

Section 5 providesassesment of ergonomic risk factors in assembly lines and Occupational Repetitive Actions (OCRA) Method also an example is solved by using OCRA solution method.

Section 6 explains the heuristic method of assembly line balancing problem.

Section 7 provides a real life problem.The application execute on a automotive company which produce cable networks. The solution is provided a numerical example to illustrate its potential benefits and the results of a brief computational experiment; and OCRA index and parametres.

Finally, Section 8 provides several conclusions and ideas for further research.

CHAPTER TWO
ASSEMBLY LINE BALANCING

2.1 Basic Principles of Assembly Line

Processing tasks: a processing task *i* (task, here after) is an indivisible working unit which has associated processing time t_i. The total work required to manufacture a product in an assembly line is divided into a set of tasks.

Workstations: are the line component where tasks are processed, and can involve a human or robotic operator, certain equipment and some specialized processing mechanisms.

Cycle time (*c*): is the time available in each workstation to complete the tasks required to process a unit of product the production rate is equal to 1/ (*c*) units of product per time unit. The cycle time is also defined as the time interval between the processing of two consecutive units.

Precedence relations: are defined by the technological precedence requirements that determine the partial order in which tasks can be performed in the assembly line. A task cannot be processed until all its immediate predecessors have already been processed. Precedence relations are normally represented by a precedence diagram.Figure 2.1 shows an example precedence graph with 9 tasks having task times between 2 and 9 (time units)(Boysen et al., 2006).

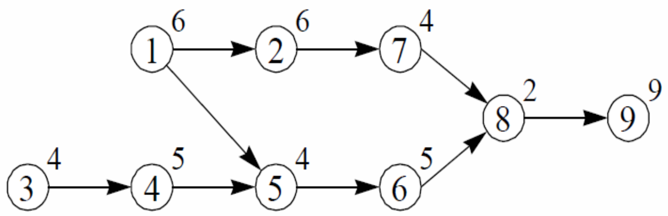


Figure 2.1 An example of a precedence graph

Workstation load: is the subset of tasks assigned to workstations.

Workstation time: is the sum of the times t_i of all tasks assigned to workstation j.

Workstation idle time: is the difference between the cycle time and the workstation load.

Line balancing: is the process of distributing the tasks among the workstations in such a way that precedence constraints and other constraints are satisfied; aiming at optimizing a given efficiency measure.

There exists a great variety of configurations involving assembly lines, which are characterized according to diverse criteria. Amongst others, these include the layout and shape of the line, the number of products and models being processed in the line, types of workstation and the variability of the task processing times(Boysen et al.,2006).

The assembly line balancing problem can be explained as the requirement to assign task elements according to precedence relations and some other constraints to each workstations on the production line in order to achieve specific objectives, such as maximizing the production rate and minimizing the number of workstations, cycle time, and slack time. Furthermore, line balancing will reduce the differences between assigned workloads. Assembly line balansing problems vary with regard to the number and variety of products, line control, variability of operation times, line layout, degree of automotion in stations, and etc. (Scholl, 1999).

2.2 Assembly Line Balancing Problem

Classic assembly line balancing problem (ALBP) is assigned the tasks which have a certain processing time considering the precedence relations to workstation, in order to optimize several objectives.

The distribution of tasks between stations depends on the priority constraints between tasks, as well as the required time unit to complete each tasks. The product is allowed to stay until the cycle time(c) ends.

Classic ALBP is divided into two main problems as Type 1 and Type 2. At type 1 problem the cycle time is constant and the goal is minimizing the number of workstation. At type 2 problem the goal is minimizing the cycle time to a constant number of work station that is determined before. So, this type of balancing problem problems is more appropriate when redesigning an existing line. Also, Type 3,Type 4 and Type 5 problems try to maximize the workload smootheness, maximize the work relatedness and maximize multiple objectives with Type 3 and Type 4, respectively.

Assembly line balancing problemsvary with regard to the number and variety of products, line control, variability of operation times, line layout, degree of automotion in stations, type of stations, and etc. (Scholl, 1999).

As an example, the mathematical model of the Type 1 problem is showed below (Scholl, 1999).

$$\text{Min} \quad \sum_{j=1}^{m_{\max}} z_j \tag{2.1}$$

Subject to

$$\sum_{k \in FS_i} x_{ik} = 1 \qquad \forall i \in V \tag{2.2}$$

$$\sum_{i \in B_k} t_i \cdot x_{ik} \le c \qquad \forall k \in \{1,\dots,\overline{K}\} \tag{2.3}$$

$$\sum_{k \notin FS_i} x_{ik} \le \sum_{k \notin FS_j} x_{jk} \qquad \forall (i,j) \in V \tag{2.4}$$

$$x_{ik} \in \{0,1\} \qquad \forall i \in V; k \in FS_i \tag{2.5}$$

i and j tasks, k workstation, K is the number of workstation, $\overline{K}$ the maximum number of workstation that is determined before, V precedence relations diagram, FS_i is the set of potential workstations that the tasks(i) can be assigned. And x_{ik} is a decision variable that is 1 if task i is assigned to workstation k, if not the value of the variable is 0.

The objective function (2.1) refers to minimizing the total number of workstations. (2.2) the quality is mean to each job can be assigned to only one station.

The inequation (2.3) provides to the station does not exceed the station time to thecycle time for all stations. The inequation (2.4) allows to control of the priorities. Fordoing such a j task the i task should be completed. Any of job j came before it in order to do the job s should be finished. The last equation (2.5) indicates that i and $k$variables are binary variables.

2.3 The Classification of Assembly Line Balancing Problem

There are three fundamental types of ALBPs according to the product mix: single-model, multi-model and mixed model. In single-model assembly lines, one homogenous product or several products with identical production process are manufactured on the sam eline. In multi-model lines, similar products are assembled in batches on the sam eline. In mixed-model lines, several versions of a basic product are manufactured on the same line simultaneously and continously.

2.3.1 According to the Number of Products or Models

Single-model line: is the classical configuration in which a single model of aunique product type is produced.

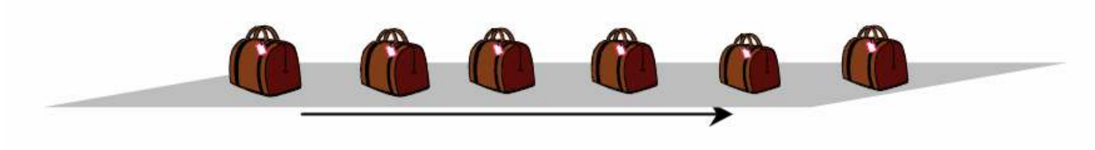


Figure 2.2 Single-model line (Kemer, 2011)

Mixed-model line: several variants of a basic product, referred to as models, are produced simultaneously in the line (see Figure 2.3). The production process does not involve setup times since all models require basically the same manufacturing tasks. Units of different models are produced in a mixed sequence.

Figure 2.3 Mixed model line (Kemer, 2011)

Multi-model line: different models with significant differences amongst one another are processed in the line. Therefore, sequences of batches are processed, containing either the same model or a group of similar models, involving intermediate setup tasks (Figure 2.4) (Capacho, 2007).

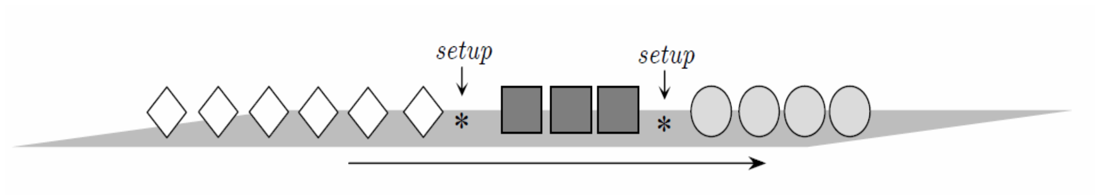


Figure 2.4 Multi-model line (Kemer, 2011)

2.3.2 According to the Task Duration

Deterministic: all task processing times are fixed and known with certainty.

Stochastic line: task processing times may be significantly affected from different sources of variability such as, for example, the ability or motivation of human operators. Therefore, the processing time of one or more tasks is considered to be probabilistic.

Dependent line: tasks processing times are not fixed but dependent, for example, on the type of workstation to which the task is assigned, on theoperator or on the processing sequence.

Dynamic line: processing times vary over time and can be reduced in successive cycles due to improvements in the assembly process or due to learning effects (for example, when operators become familiar with the tasks(Capacho, 2007).

2.3.3 According to the Line Shape or Layout

Serial lines: products units are processed throughout a group of workstations that areconsecutively arranged in a straight line such as, for example, a conveyor belt (Figure 2.5)

Figure 2.5 Serial line (Ford assembly line, 1913. The magneto assembly line)

Two-sided lines: consist of two serial lines in parallel, in which pairs of opposite workstations (left-hand side and right-hand side) process simultaneously the same workpiece. This configuration is commonly found in the automotive industry (Figure 2.6). Some taskscan be assigned only to one side (e.g. mount the left car wheel), some tasks can be assignedto either side (e.g. install the hood ornament), and some tasks must be assigned to both sidesof the line simultaneously (e.g. install the rear seat).

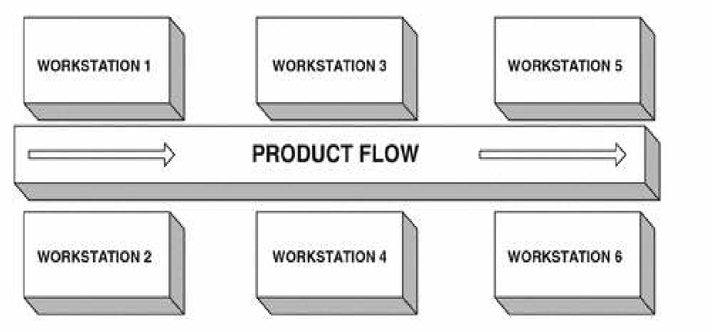


Figure 2.6 A two-sided line (Baykasoğlu, & Dereli, 2006)

Parallel workstations: in this case two o more workstations are put in parallel; hence, thework pieces can be distributed between several workstations that perform an identical set oftasks.

Parallel lines: this type of configuration can be considered when the production system involves multiple products, in which each line is designed for one product or family of similar products (Figure 2.7).

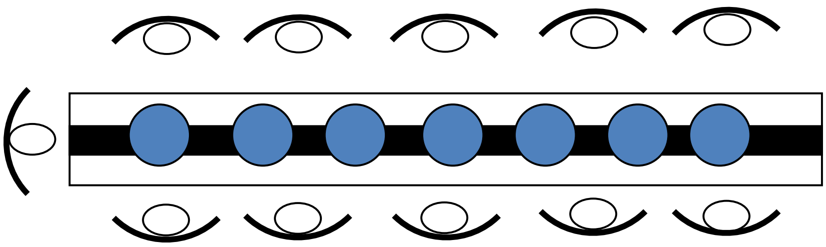


Figure 2.7 Parallel lines

U-Shaped lines: the workstations are arranges in a U-shaped line. Both tops of the line are closed to each other forming anU-Shaped line (Figure 2.8). The workstations may work during the same cycle on two or more workpieces at different positions on the line.

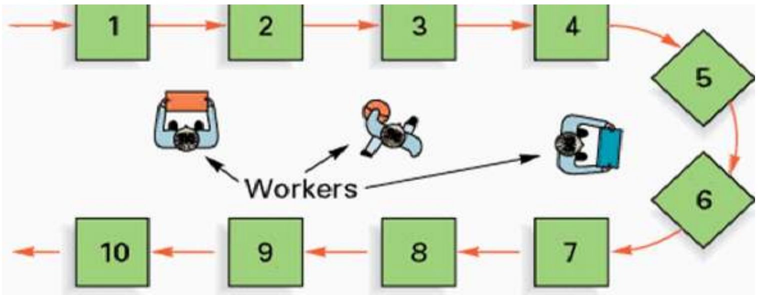


Figure 2.8 U-shape lines

Circle/closed lines: in this type of lines the workstations are arranged around a circular conveyor belt (or similar mechanism), as can be seen in Figure 2.9. A workpiece moves around being processed as it visits the workstations, until the last task have been performed (Capacho, 2007).

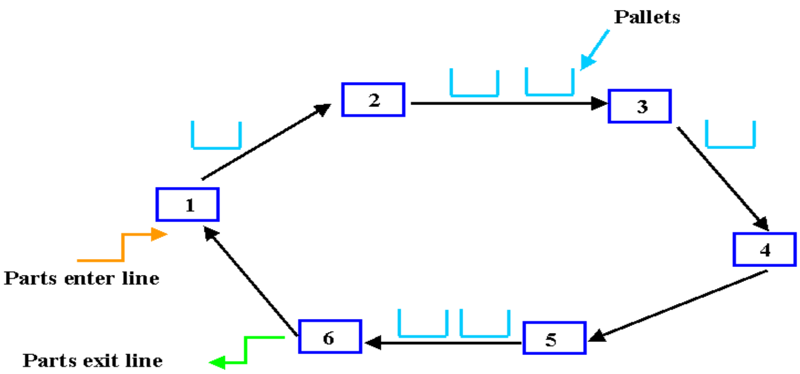


Figure 2.9 Closed line

2.3.4 According to the Workpieces Flow

Synchronous lines: in synchronous lines, also referred to as paced lines, all workstations have a common cycle time. Therefore, all workstations start processing at the same time and advance the workpieces simultaneously. Synchronous lines have a fixed production rate (Figure 2.10).

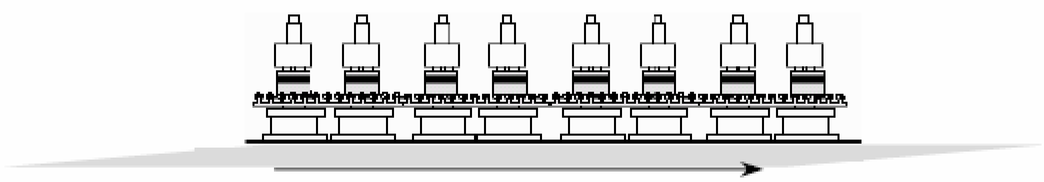


Figure 2.10 Synchronous line (Kemer, 2011)

Asynchronous lines: in these lines all workstations can work at different speeds; thus, workpieces are transferred whenever the required tasks are completed. The workstations are linked by buffers to store the workpieces that cannot advance to the next workstation due to it is processing another workpiece (Figure 2.11).

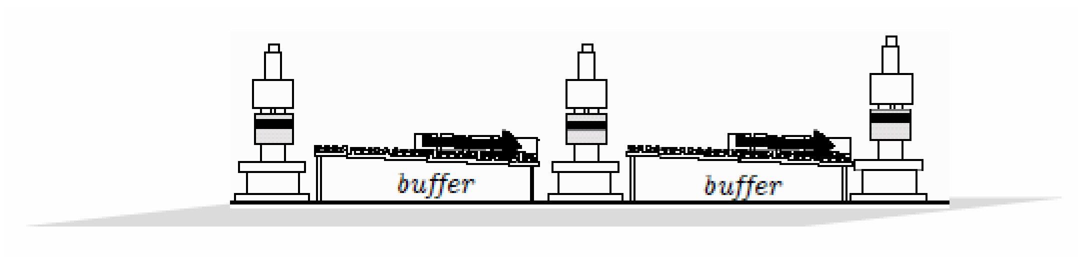


Figure 2.11 Asynchronous line (Kemer, 2011)

Feeder lines: feeder lines are supplementary lines that provide a main line with subassemblies. Figure 2.12 shows an example of an assembly process of an aeroplane, which consists of four lines feeding the main line (Capacho L.,2007).

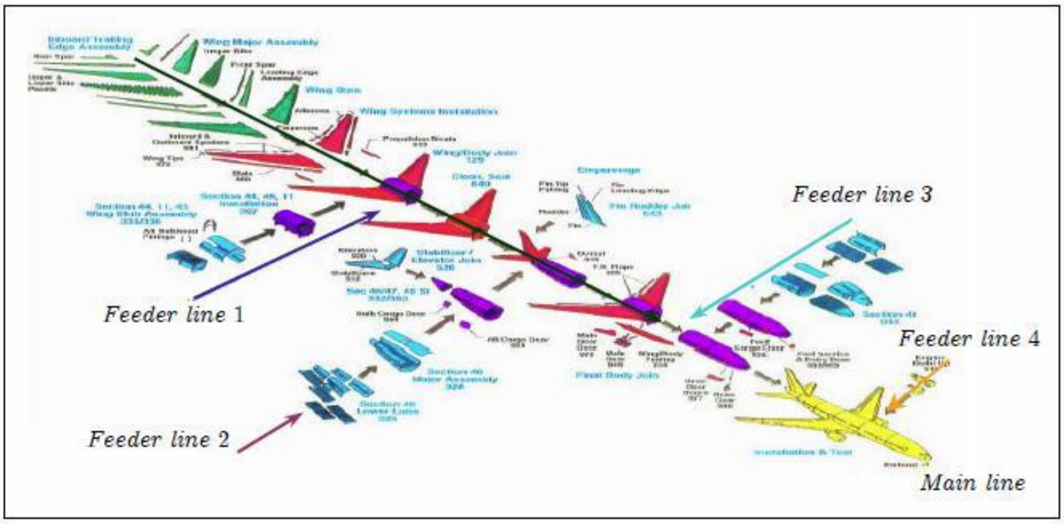


Figure 2.12 Feeder lines. (Kemer, 2011)

2.3.5 According to the Level of Automation

Manual lines: in manual lines the tasks are performed by human operators. These lines are common when workpieces are fragile or are of special importance. Harley Davidson‘s motorcycles, for example, are 100% assembled by hand as shown in Figure 2.13.

Figure 2.13 Manual line

Figure 2.14 Robotic line

The characterization of line, to a great extent, determines the type of balancing problem that is to be solved. For example a single-model, serial, paced, deterministic line merely entails the assigment of tasks to the workstations -the simplest balancing problem. However, for other line configurations the balancing problem comes to get her with a problem of sequencing the models, wheras a multi-model line also implies a lot sizing problem. Paralel lines involve a decision problem concerning the number of lines that needs to be installed. Robotic lines (Figure 2.14), on the other hand, involve the assignment of both tasks and robots to the workstations.

Asynchronous lines requires of the positioning and dimensioning of buffers:

- vand whenever feeder lines are considered, the production rates of the available lines have to be synchronized (Capacho, 2007).

It is evident that industrial systems involve a great variety of characteristics and problem variations. However, due to their complexity, most literature studies on production and manufacturing have addressed problems which do not consider many of the requirements and constraints present in real systems. However, in the last years a considerable effort has been done towards filling the gap between problems addressed in research works and real-world applications (Capacho, 2007).

2.4 The Assembly Line Balancing Problem of the Study

In 1900s, assembly line manufacturers produced low variety of products in high volumes. Most of the companies considered only one objective such as maximizing throughput or minimizing costs, in those days. However, the assembly line concept has evolved during the decades. In today's highly competitive business environment, companies have the focus on customer needs and voices. Thus, the companies have to cope with multiple objectives simultaneously. Some of the real life objectives can be listed as maximizing throughput, minimizing late delivery, minimizing setup times, minimizing inventory, minimizing cycle time, and etc. This is why the thesis is multi-objective assembly line optimization.

CHAPTER THREE
LITERATURE REVIEW

3.1 Introduction

For this study, an extensive literature research is done about assembly line design, line balancing, assignment of work and worker considering ergonomic risk factors work, where national and international R & D activities carried out in various industries on these subjects.

The developed solution methods were applied to the test problems under the unrealistic and restrictive assumptions. And the real problem applications have been ignored.

In recent years, there has been great interest in the development of intelligent solution methods for worker and job assignment in the assembly line balancing. There are lots of study about this research area. Some articles and thesis are summurized andorganized according to their topics in this chapter.

3.2 Ergonomics Science

Ergonomics is the scientific discipline concerned with the understanding of physical and psychological effects of workplace on worker. The main aim of ergonomic is protect employees health from repetitive harmful working environment that will cause occupational diseases. In this study we consider ergonomic factors for the ALBP.

Ergonomics is defined as the applied science of equipment design, as for the workplace, intended to maximize productivity by reducing operator fatigue and discomfort. Benefits provided by ergonomics application in assemblysystems design are first of all linked to the reduction inoccupational injury risks and to the improvement of health condition and motivation of human resources. Secondly,ergonomics improvements permit to improve processquality and operators productivity. The link between investigated in published literature: Drury C.G., (2000) analyzes therelationship between ergonomics and qualityimprovements of the production system and provides aguideline for a discipline that includes quality andergonomics. Gonzàlez et al. and Eklund study therelationship between ergonomic performance and qualityby empirical applications in industrial contexts. It is clearthat attention to workplace ergonomics and reduction of Work-related musculo-skeletal disorders (WMSD) areworth while Carey et al. 2002. For these and other reasons, the linksbetween assembly system design and balancing problemsand ergonomics evaluation techniques achieve strategicimportance in practice. Previous projects havedemonstrated the extra value of combining assemblyengineering with ergonomics (Van Lingen et al.,2002).

De Looze et al. (2003) apply an integrative approach bringing together assemblyengineering and ergonomics disciplines in order to identifybottleneck and offer improvements. Usually ergonomicsevaluations are performed by ergonomists, and workplacelayouts are designed by planning engineers. Suchpractices have been somewhat unsatisfactory both forresults and productivity (Carey et al., 2002).

They need to be integrated. Computer aided workplace design and postural analysis software tools permit to simplify the analysis and create a virtual man-model Carey et al. 2002, while traditional procedures are still time-consuming and often unfeasible in practice. Published literature onassembly systems design often focuses on balancing and sequencing procedures and addressing the mixed-modelassembly line balancing problem (MALBP) in different layout configurations, developing exact, or heuristic methods. Most methods address the balancing problem of traditional serial assembly systems and, in some cases; they allow the use of identical parallel workstations at each stage of the serial system. A considerable group of authors investigates the balancing problem in case of U-shaped layouts. A few studies address the fixed position layout and the two-sided layout in order to solve particular assembly cases. A number of papers aim to optimize a preexisting system, without scrutinizing the workplace ergonomics or task times value feasibility and correctness (Becker & Scholl, 2006). Experiences collected from the authors lead to recognize that task times analysis procedures are not sufficient incase of time losses due to workers disability. Thus, a workplace solution that seems to provide the lowest cycle time value might not be able to respect the schedule at all time or might increase disability time for the operators.Anyway, the realization of ergonomic potential seems to depend on management culture, as well as on factors outside the company (Bao et al., 1996).

3.3 Effects of Ergonomic Conditions in Manufacturing Environment

Nowadays the effect of ergonomic factors is such an important problem in working life. The ergonomic risks that occurs in workplace cause lots of damage on the health of employees. The problem not only effect on the employees health but also on employers financial gain. Therefore, we study on ergonomic risk factors in human lifes while working in this thesis.

3.4 Goals of Ergonomics Business Systems

Specifically, some of the goals of ergonomics are:

- Applied in the equipment design, as for the workplace, intend to maximize productivity by reducing operator fatigue and discomfort. Benefits provided by ergonomics application in assembly systems design are first of all linked to the reduction in occupational injury risks and in the improvement of health condition and motivation of human resources.
- To accommodate differences in strength and body size among different workers.
- To remove barriers to productivity and performance.
- Continuous improvements and breakthroughs.

The reduction of injuries and illnesses related to inadequate workplace design requires a risk management approach combined with the application of engineering solutions.

Risk management begins with the identification and measurement of workplace ergonomics risk factors. After risk factors in the workplace are well understood, equipment and workstations can be redesigned to minimize exposure to the risk factors. The application of engineering solutions to reduce exposure to ergonomic risk factors requires a two-pronged approach: retrofit solutions are applied to existing work stations and equipment, and the design of new workstations and equipment encompasses ergonomic criteria (―fit once repeat many) (Smith, 2003).

3.5 Ergonomic Risk Factors in Assembly Line Balancing Problem

In recent years, there has been great interest in the development of intelligent solutions for worker and job assignment on the assembly line design. There can be found lots of study about this research area. Some articles and thesis are summurized here.

Widyadana (2009), expand the U-type linebalancing using goal programming for multi objective model to minimized the number of temporary workers and number of cycle time in each station. Different amount of time for temporary worker to accomplish their tasks were generated.

Moreira et al. (2012) analyzed assembly lines in sheltered work centers. Different from the well-known simple assembly line balancing problem, the task execution times vary according to the assigned worker. They developed a constructive heuristic framework based on task and worker priority rules defining the order in which the tasks that workers should be assigned to the workstations. Present a number of such rules to compare the performance of workers to across three possible uses: as a stand-alone method, as an initial solution generator for metaheuristics, and as a decoder for a hybrid genetic algorithm. For a conclusion their heuristics are fast, they obtained good results as a stand-alone method.

But in the assembly line balancing problems when assigning workers at stations there are a few articles which considers ergonomic factors. Studies in this field are outlined here.

Lango, Mirabelli and Papoff (2006) developed an effective design of an assembly line for heaters production by taking into consideration work measurement, line balancing and ergonomic problems. As the assembly line is 20ork not in existence and no data are available, it is quite difficult to evaluate, for each assembly line workstation, the work assignment, the assembly times as well as the effect of ergonomic risks such as musculoskeletal disorders, wrong working postures, etc.

For assembly line balancing traditional procedures take into account only task time analysis and precedence relations, while human postures evaluation is often not integrated in these techniques. Battini et al. (2007) developed a systematic approach to allow assembly system design including ergonomics guidelines to investigate how ergonomics and assembly system configurations are intimately related in practice. Generate a conceptual framework works of assembly system design, in conjunction with ergonomics optimization of the work place. They used a simulation software to validate the procedure and support the theoretical framework.

Otto and Scholl (2011) show that re-balancing often leads to a substantial mitigation of ergonomic risks. In their cases, they increase in number of stations was required, such a solution was found after just about 4% increase in the line capacity. Further, our computational experiments indicate that, in general, with each new working station the improvement of ergonomic risks diminishes.

Scholl, Boysen, & Fliedner (2008) give an alternative representation of the problem, formulate an improved mixedinteger program and propose a solution approach based on SALOME, an effective branchand-bound procedure which is well-known Simple ALBP. Computational experiments indicatethat the proposed procedure is successful in finding optimal solutions for small- and medium-sized problem instances and rather good heuristic solutions for large-scaled instances.

Simmons et al. (1997) describes recent research in the application of Virtual Reality to two important manufacturing and assembly tasks which have a direct influence on the speed of introduction of new products. The tasks are the production of planning documentation for assembled products and the design and planning of the cable harnesses which form part of all electro-mechanical assemblies. A Virtual Reality system has been described which allows the user, in an immersive virtual environment, to perform the routing process intuitively and efficiently. This approach focuses on the user's expertise to complete the task rather than trying to automate the procedure. The system also automatically logs the details of the routing process which can be used to create a bill-of-materials and two dimensional schematics of the harness.

As a result of research there are not found a assembly line balancing study on a production of harness system in the literature. In this study we believed to be a guiding example that can be useful to the literature of life sciences.

CHAPTER FOUR
HARNESS PRODUCTION AND ASSEMBLY LINE BALANCING PROBLEM

4.1 Harness Production Assembly Line System

Harness is an integrated number of cables that transmits electricity from one point to another. In 1950s harness has some simple electricity conduction funtion but nowadays it is enable heating, air conditioning, listening to radio, security, etc. A harness that is produced at the mentioned company is illustrated in Figure 4.1.

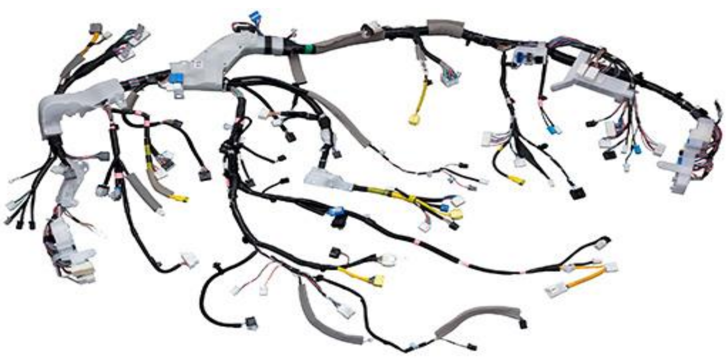


Figure 4.1 Harness of an automobile (Baykasoğlu et al., 2013)

Figure 4.2 represents cable network system of an automobile. Harness of the automobile looks like blood vessels of human body. Just like blood vessels transferring blood, harnesses also transmit electricity for automobiles.

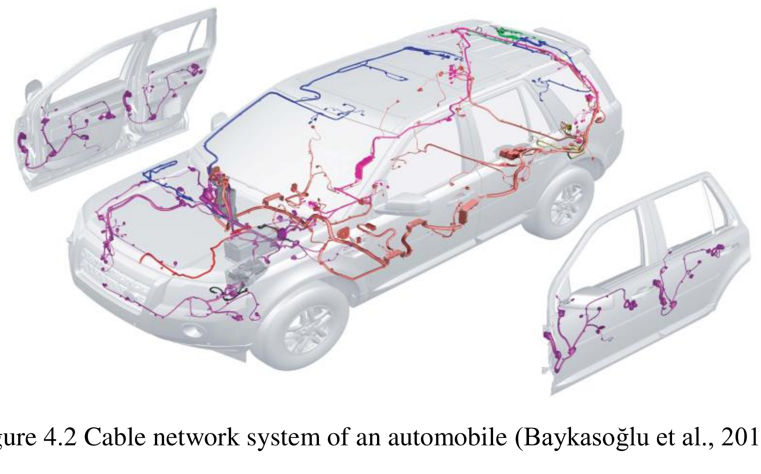


Figure 4.2 Cable network system of an automobile (Baykasoğlu et al., 2013)

To provide the customer demands many immediatly different parts are produced at the same line.

The production system of the company works in 3 shifts per day. Assembly area is divided into four main sections. They are subassembly line, the main assembly line, the implementation of enriching and electrical testing.

At the subassembly line stations to feed the main assembly line various electrical bonding process is done according to the desired properties of cables. Also assembly process is done at the main assembly line, too. Here in Figure 4.3 there is a sub-assembly line, in Figure 4.4 there is the main assembly line. Also in Figure 4.5 we can both see the sub and main assembly lines, together.

Figure 4.3 The subassembly line

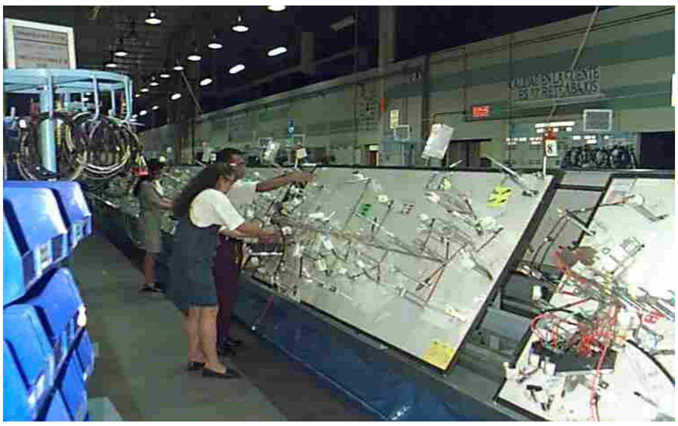


Figure 4.4 The main assembly line

Figure 4.5 The layout of the sub and main assembly lines

To work in a relaxed way the cables are positioned vertically. Then harnesses are being prepared for assemblying on the main board. According to the production features, the production of some parts are started and also ending at the main line.But for some parts assembly operation is started at the sub-assembly line and ended at the main assembly line.

In the present situation the production process is started with the technical drawings which is cretaed according to the customer expectations.

Drawings, material specifications and special file documents are sent to the Production Engineering department. By using the documents the required analysis are performed to determined the work divisions. So some operations are done at to the sub-assembly and some are at the main assembly line. Also to achieve the desired porduction conditions, the operator numbers are calculated. Then the workers are assigned to the assembly line. Harness production, is divided into two main operations: cutting and assembly. First cable rolls are came to the stock area that calls supermarket, then they are cut to the desired lenght. The cables are transported to the the production area by car (see Figure 4.6).

Figure 4.6 The transportation car

Not only the cables but also the other needed materials are transported to the production area by cars (see Figure4.7).


Figure 4.7 The material transportation car

Harness production assembly line is an example of closed assembly line system. The production flow is given in Section 4.1 in detail. The whole view of a harness assembly line is given in Figure 4.8.

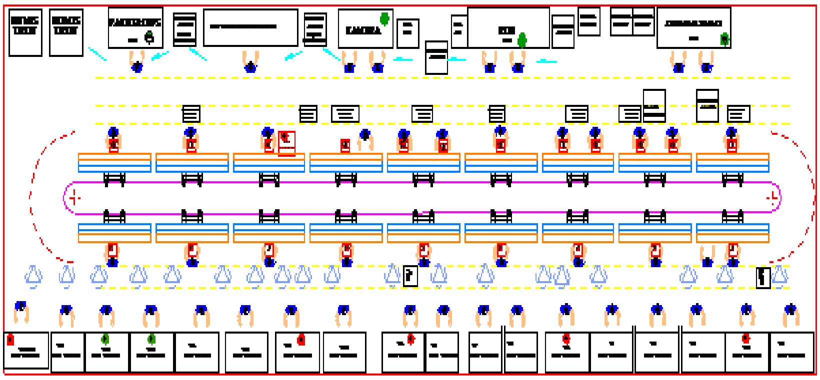


Figure 4.8 The whole view of a harness assembly line

4.1.1 Harness Production Flow Chart

The other production steps are described by the the production flow chart of the company at the Figure 4.9.

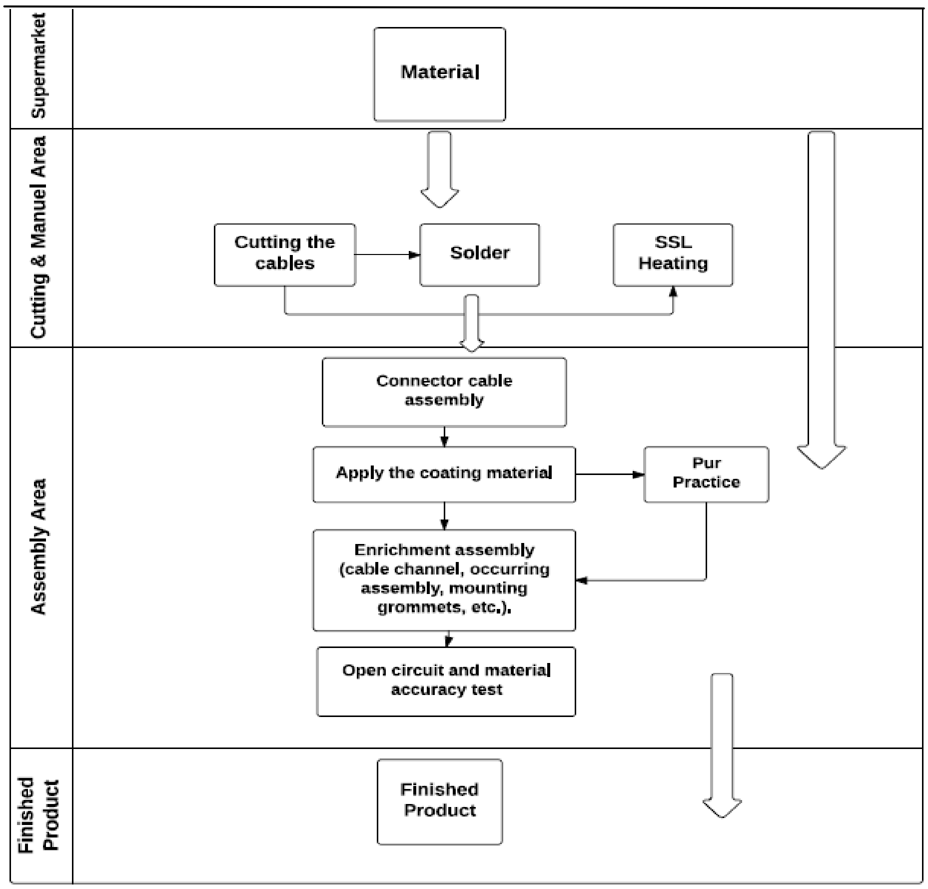


Figure 4.9 The production flow chart of the company

The parts supplied from the material warehouse called supermarket are distributed to the cutting and manual production area. At this area cutting, solder and heating operations are done. At assembly lines routing, assemblying and taping (coating material application) procedures are performed. Assembly line moves in order to the cycle time that is changed to model to model. Then the materials are came to the assembly line. At this area enrichment operations are done. At the end of these operations harness is tested electrically. If the electrical test is succeeded harness is transported to the finished good area.

4.2 Harness Production System Literature Review

In the literature, there are a limited number of studies about the production system of harness. In the existing studies in the production of the harness are about planning, performance and design.

Assembly line balancing problems in harness production are briefly described only just below a title at a PhD study (Simaria, 2006). The author indicated that assembly line balancing problem of the harness production is in n-dimensional assembly line class, and did not give more information about this area.

Aguirre E. & Raucent B. (1994) presented an economic performance analysis of harness assembly method. Extremely labour-intensive and tedious process. Automatic or robotized wiring systems have therefore been developed that prepare the wire, route the wires and lace the branches automatically. The authors described the assembly systems but do not give any economical comparisons. There is therefore a need for an economical comparison of the harness assembly methods used in industry (e.g. manual, semi-automatic and automatic) as well as those currently developed in laboratories.

Simmons (1997) has the application of Virtual Reality to two important manufacturing and assembly tasks which have a direct influence on the speed of introduction of new products. The tasks are the production of planning documentation for assembled products and the design and planning of the cable harnesses which form part of all electro-mechanical assemblies.

Another study of Jiang et al. (2010) Advanced Robotics Elemental Technologies is the short name NEDO Strategic Development Projects funded by harness robot mounted on an automobile assembly line. The aim of this study is investigating the possibility of commercialization of assemblying harness with the help of robotics. Therefore the developted prototype robot system is designed on a cable network assembly system that has referenced by Suzuki Motor Company in practice.

CHAPTER FIVE
ASSESMENT OF ERGONOMIC RISK FACTORS IN ASSEMBLY LINES

5.1 Ergonomic Risk Assesment Techniques

In literature there are some techniques that is used to solve ergonomic problems. They are Quick Exposure Check (QEC), Rapid Upper Limb assessment (RULA), European Assembly Worksheet (EAWS), Rapid Entire Body Assessment (REBA), National Institute for Occupational Safety and Health (NIOSH) and Occupational Repetitive Action (OCRA). In this thesis we used OCRA technique to solve the case study.

5.1.1 National Institute for Occupational Safety and Health (NIOSH)

The NIOSH equation was developed in 1981 by the NationalInstitute for Occupational Safety and Health for risk estimation ofworking conditions, where manual handling activities are the mainsource of risk and lifting comprises more than 90% of manual handlingactivities (Waters et al., 1994).

The NIOSH equation communicates a lifting index LI that showsthe relation of the current load weight to the recommended loadweight limit:

$$LI = \frac{\text{Load weight}}{\text{Recommended weight limit}} \tag{5.1}$$

The higher the lifting index, the higher percentage of the workforceis likely to be under risk for developing low back pain. The recommendedweight limit is calculated depending on lifting conditionsTS, e. g. vertical travel distance of hands or degree of asymmetryin posture, and the frequency of lifting FM:

$$\text{Recommended weight} = TS \times FM \tag{5.2}$$

The frequency multiplier FM is calculated based on the average number of lifts per minute. It takes into account the duration ofthe lifting activity, as well as the vertical height of the lift fromthe floor.

5.1.2 European Assembly Worksheet (EAWS)

The European Assembly Worksheet (EAWS) underlies ergonomics tools used by such automobile producers as Volkswagen andFIAT and has a similar structure as some other methods appliedin manufacturing: NPW used by Opel, DesignCheck used by Daimlerand IAD-BkB widely used in German metal and electrical goodsindustries.

EAWS assesses postures, action forces, manual material handlingas well as other whole-body risk factors and repetitive loadsof the upper limbs (Schaub et al., 2010). The resultsof EAWS estimation are two aggregate risk values: risk points (*RP*)for the whole body and risk points for upper limbs.

The higher these risk points are, the higher is the risk of musculoskeletaldiseases for a worker. It is recommended to interpret arisk value of 0–25 points as a low risk zone (green), of 26–50 pointsas a zone of possible risks (yellow) and above 50 points as a highrisks zone (red).

Risk points for the whole body are computed from fourindices:

$$RP_{whole\ body} = PI + MMHI + FI + Extra\ points \tag{5.3}$$

Posture index *PI* sums up risk points for specified kinds of postures.Risk points for each posture depend nonlinearly on frequency orduration of the posture within the cycle time. Additional pointscould be given for twisting, lateral bending and extended reaching.

Manual material handling index *MMHI* is a sum of risk points *RP*for lifting, holding, carrying and pushing or pulling. These constituentsof the *MMHI* as well as action forces index *FI* depend on theforce level multiplier *FoM* corrected by work conditions and durationof exposure, expressed either in duration, frequency or lengthpoints:

$$RP_{lifting} = FoM * \text{Frequency points} \quad (5.4)$$

$$RP_{holding} = FoM * \text{Duration points} \quad (5.5)$$

$$RP_{carrying} = FoM * \text{Length points} \quad (5.6)$$

$$RP_{pushing\ or\ pulling} = FoM * \text{Lenght points} \quad (5.7)$$

$$FI = FoM * (\text{Frequency points or duration points}) \quad (5.8)$$

Extra points are given to risk factors that were not or not enoughconsidered in the EAWS calculations above (e.g. working on movingobjects).

The second aggregate risk value of EAWS, risk points for upperlimbs, is based on force points *Fo* and posture points *Po*, that dependnonlinearly on the duration of exposure, as well as additionalpoints *Ad*. Organization specific parameters *OS* depend on the shiftduration, as well as duration and frequency of rest pauses withinit:

$$\mathrm{RP}_{\text{upper limbs}} = OS * (\mathrm{Fo} + \mathrm{Po} + \mathrm{Ad}) \quad (5.9)$$

5.1.3 Quick Exposure Check (QEC)

The Quick Exposure Check (QEC) was developed to enable health and safety practitioners to undertake assessments of the exposure of workers to work-related musculoskeletal risk factors (WMSDs). The primary development of the tool is documented as a HSE Contract Research Report (Li and Buckle, 1999). This initially involved a detailed review of the scientific literature concerning risk factors for musculoskeletal disorders and an investigation of user needs. These provided the basis for the construction of QEC using a participatory approach with input from approximately 150 health and safety practitioners. The tool was then evaluated in both the laboratoryand workplace to determine its reliability and validity. Pragmatic compromises had to bemade between scientific validity and usability. These have remained a source ofpotential scientific criticism, but the tool has been well accepted and used by manypractitioners.

QEC, therefore, is a tool designed for and by practitioners. It assesses exposure andchange in exposure to the main risk factors for WMSDs. By assessing exposure asopposed to risk, the effectiveness of workplace interventions can be evaluated withoutwaiting for changes in the prevalence of WMSDs to become evident.

The main benefits of the Quick Exposure Check (QEC) are that it:

- provides health and safety practitioners with a user friendly assessment tool withgood validity
- has been shown to be straightforward to use
- helps persuade organisations to make ergonomic changes
- is compatible with HSE risk assessment methods
- involves both the practitioner and the worker in the assessment, thereby providing afuller understanding of working practices.

5.1.4 Rapid Upper Limb Assessment (RULA)

The RULA Method (Rapid Upper Limb Assessment) was developed by McAtamney, and Corlett, (1993) is particularly used to evaluate the WMSD risk to workers engaged sedentary tasks such as workers at video terminals or the risk from other tasks in which the operators sits or the risks for workplace in which the worker stands for a large part of the time. The analysis input data are body posture (head, trunk, upper limbs), the force used, the type of movements or actions performed, repetitivity. As with the REBA method, each examined area or factor is assigned a score that grows with the risk that is inherent in the factor.

This is particularly useful during the step of redesigning the workplace as it is easy to identify the factors that most contribute to "increasing" the risk level. As with the REBA method, the risk index obtained from the RULA analysis indicates the risk level and the urgency with which corrective measures should be taken, with the score increasing the higher the risk. It should be used according to the same criteria as for the REBA method.

5.1.5 Rapid Entire Body Assessment (REBA)

The REBA Method (Rapid Entire Body Assessment) was developed by Hignett, and McAtamney (2000) to assess the WMSD risk of workers in health facilities and other service industries. The analysis input data are the posture of the entire body (head, trunk, upper and lower limbs), the force used, the type or movements or actions performed, repetitivity and grasp conditions. A score is assigned to each area or factor examined that increases according to the risk that is inherent in the factor. This is particularly useful during the workplace redesigning phase because it is fairly easy to identify the factors that most contribute to "increasing" the risk level. The risk index that is obtained from the REBA analysis indicates the existing risk level and the urgency with which corrective measures should be taken. The higher the score, the greater the risk.

This method examines all the parts of the body and is a "complete" tool in as much as it enables risk situations for the various parts of the body to be detected as well as for the upper part of the body (for example the trunk, neck…). It can be used in all situations and in particular for the WMSD analysis of staff involved in handling hospitalised patients. It can also be used in those situations in which any other method gives "borderline" results in which a situation of certainty arises or in all the situations in which anomalous situations arise as an acceptable calculated risk level and personnel show discomfort. In all these cases, applying several analysis methods is advisable.

5.2 Occupational Repetitive Actions (OCRA) Method

Occhipinti (1998) is developed OCRA method and used it to solve ergonomic problems. It analyzed the upper limps of the body such as hand, wrists, elbows and shoulders.

It is an approach to calculateergonomic risks of the work-related musculoskeletal disorders. Todat OCRA is approved by ISO (ISO 12228-3) and CEN (EN1005-5) standards to identify and measure the risk factors during working on repetitive tasks. The main aim of ergonomics is to protect occupational health and safety and prevent long term diseases. Repeptitive unfavorable working conditions cause some diseases such as, repetitive strain injury, carpal tunnel and joint elbow syndromes related with hand, elbow, wrist and shoulders.

OCRA Index is an appropriate method that analysis ergonomic risk which is caused because of repetitive tasks. OCRA metod is especially used for research and solve the ergonomic problems of the upper limbs of the body such as hands, wrists, elbows and shoulders. Also it is taken into consideration of the body separately by left and right. The OCRA index calculation is:

$$\text{OCRA index} = \text{Actual frequency} / \text{Recommended frequency} \qquad (5.10)$$

In the OCRA describtion the technical actions are basic manual actions that have to be executed within the work cycle, such as holding, turning, pushing, cutting, moving, controlling, rotating, painting etc. Frequency of actions and recommended frequency are calculated as below.

$$\text{Actual frequency} = \text{Number of technical actions within a cycle/Station time*60} \qquad (5.11)$$

$$\text{Recommended frequency} = CF * PM * FM * RM * ARF * (RcM * DuM) \qquad (5.12)$$

CF is the constant of technical actions per minute. PM is the posture multiplier. FM is the force multiplier. RM is the repetitiveness multiplier. ARF is additional risk factor. RcM is the lack of recovery period multiplier. DuM is the multiplier for the overall duration of repetitive tasks during shift. CF is a constant value (European Committee for Standardization, 2007). All multipliers except CF are between 0 – 1. For ideal conditions the parametres are equal to 1. But when the risk level increases the multipliers decrease to 0.

5.2.1 OCRA Index Parameters

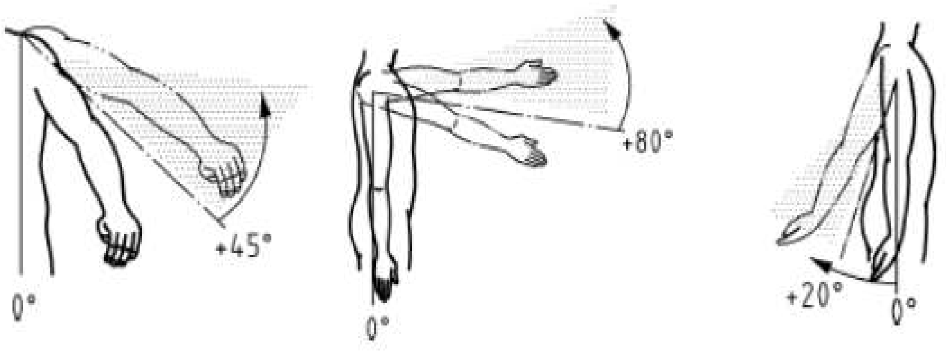
The parameters which are expressed as follows is used to calculate OCRA Index.

5.2.1.1 Constant of Frequency Multiplier(CF)

Frequency multiplier which is the first term of the required frequency is assumed to be 30 for ideal conditions. Ideal conditions illustrates a working environment that a shift takes 480 minutes at most, and there are at least 1 lunch break of 30 minutes and 2 coffee breaks of 10 minutes (1 must be before lunch break).

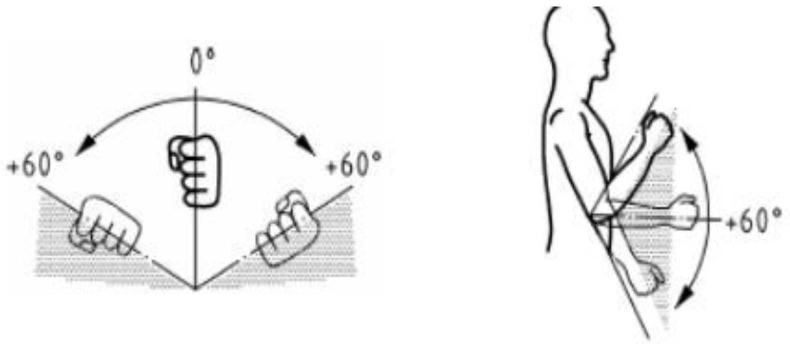
5.2.1.2 Posture Multiplier (PM)

Posture is the position and movements of the upper limbs of an operator in order to execute a task. While analyzing the posture and movement of a worker hand, elbow, wrist and shoulder is considered. Some examples of awkward postures for shoulder, elbow, wrist and handa reillustrated in Figures 5.1, 5.2, 5.3 and 5.4, respectively.



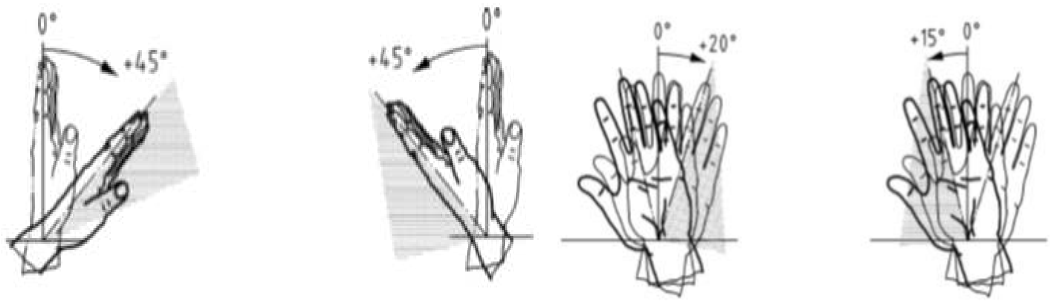
a) b) c)

Figure 5.1 Examples for awkward postures of shoulder a) Lateral elevation abduction/adduction (awkward posture > 45^{o}) b) Frontal elevation flexion (awkward posture > 80^{o}) c) Extension (awkward posture > 20^{o}) (European Commitee for Standardization, 2007)



a) b)

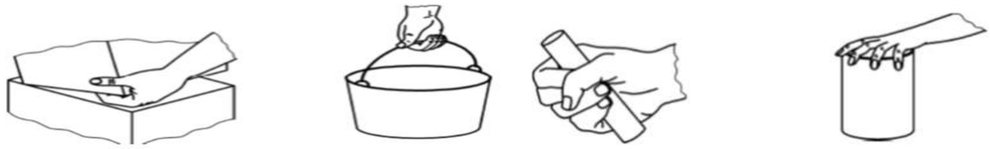
Figure 5.2 Examples for awkward postures of elbow a) Palmar flexion (awkward posture >60^{o}) b) Dorsal extension (awkward posture >60^{o}) (European Commitee for Standardization, 2007)



a) b) c) d)

Figure 5.3 Examples for awkward postures of wrist a) Palmar flexion (awkward posture >45^{o}) b) Dorsal extension (awkward posture >45^{o}) c) Ulnar deviation (awkward posture >20^{o}) d) Radial deviation (awkward posture >15^{o}) (European Commitee for Standardization, 2007)

a)



b) c) d)

Figure 5.4 Examples for awkward postures of hand a) Pinch b) Hook grip c) Power gripd) Plamar grip (European Commitee for Standardization, 2007)

The posture of every single operation is analyzed for both left and right side of the body. The position of the posture is divided into portion of the cycle time of a task. If the portion of the cycle time is getting high the risk of the posture increase linearly. The risk of the posture is relevant to awkward postures and their cycle time percentages. The risk table is given in Table 5.1.

Table 5.1 Posture multiplier(PM) releated to awkward postures and their corresponding cycle time percents

Awkward Posture		**Cycle Time Percent**			
		%1-%24	%25 -%50	%51 -%80	> %80
Severe	Elbow supination (≥60) Wrist extension / flexion (≥45) Hand pinch / hook grip / palmar grip (wide span)	1	0.7	0.6	0.5
Mild	Elbow pronation / flexion / extension (≥60) Wrist radio / unlar deviation (≥20) Hand power grip with narrow span (≤2 cm)	1	1	0.7	0.5

The posture is divided to 2 main parts: Mild and Severe. Doing a task that has a mild posture is easy to do than a severe posture work. You don not have to much force to do. It is explainedon the Table 3.2 with an example. A worker who is doing a task with the awkward posture of elbow pronation(≥60) and the cycle time percent of the task operation time is between %25 - %50 then the posture multiplier is 1. But if the cycle time of the task is greater than %80 the posture multiplier is equal to 0,5.

5.2.1.3 Force Multiplier (FM)

You should have force to do a task which has the physical effort. To calculate the OCRA index we should consider the force by using some value that explain the function of the force multiplier parameter on work. The force multiplier is between 0 – 1. If there is no need to any force the multiplier is equal to 1 but when th eforce need is higher the multiplier value is getting low to 0. For different force using here is the force multiplier value listed below.

Table 5.2 Force multiplier value for different use of force

Average Force Level (%)	**5**	**10**	**20**	**30**	**40**	**50**
Borg Value	0.5	1	2	3	4	≥5
Score	very, very week	Very week	week	moderate	somewhat strong	Strong / very strong
Force Multiplier Value	1	0.85	0.65	0.35	0.2	0.01

5.2.1.4 Repetitiveness Multiplier (RM)

Repetitiveness occurs due to executing repetitive tasks at high frequency. If the cycle time is greater than 15 seconds and / or the same technical actions of upper limbs are operated less than 50% of the cycle time, the repetititve multiplier is equal to 1. If the multiplier is high the value of it will be 0.7.

5.2.1.5 Additional Risk Factor (ARF)

The additional risk factor are other risk factors different from the main risk factors that work due to the occupational nature. We can give some example to the additional risk factors like listed below.

- Exposure to cold or hot while working,
- Exposure to noise,
- The use of gloves,
- Requirement for sudden or fast movements,
- The use of vibrating tools etc.

The Additional Risk Factor is relevant to cycle time percentages. If the cycle time percent is getting high the additional risk factor value is getting low inversely. Table 5.3 is shown the value below.

Table 5.3 Additional risk factor value

Cycle Time Percent	≤ 25%	26% - 50%	51% - 80%	> 80%
Additional Risk Factor	1	0.95	0.90	0.80

5.2.1.6 Lack of Recovery Period and Number of Duration of Repetitive Tasks within a Shift (RcM & DuM)

Lack of Recovery Period and Number of Duration of Repetitive Tasks value is relevant to the environment of the working conditions. For the ideal working conditions that is accepted to a shift taking 480 minutes at most, and at least 1 lunch break of 30 minutes and 2 coffee breaks of 10 minutes. The recovery period multiplier and the multiplier *RcM* and *DuM* take the values 0.6 and 1, repectively overall duration of repetitive tasks during shift.

5.2.2 Evaluation of the OCRA Index

The OCRA index parametres are explained in section 5.2.1. By using these parametres according to the task properties we divide OCRA index to 3 zones that taken colors as their risk levels. Interpretation of the OCRA index represented in Table 5.4.

Table 5.4 OCRA index

OCRA Index	Zone	Risk Levels
≤ 2.2	Green	Low Risk
2.3 – 3.5	Yellow	Acceptable Risk Level
> 3.5	Red	Not Acceptable Risk Level

The Ocra Index evaluation of the results are below.

- If OCRA index is smaller than 2.2, it means the risk level is in a low risk area. The effects of internal business areas are acceptable.

- If OCRA index is between 2.3 and 3.5 the work place ergonomics is acceptable.

- If the index is greater than 3.5 it takes place in red zone. The practitioners should be careful and take some extra preventions.

When the index value increases so the risk level is proportionally increase. To improve the working conditions, the movements that performed during working should be kept under control with the help of analytical measurements data. (Occhipinti E.&Colombini D. , 2001)

5.3 Application of OCRA Index to Measure the Effect of Ergonomic Risk Factors: An Example

In this section, a numaric example is given that will explain the using of OCRA index in an assembly line. The example is solving the ALBP by using OCRA parametres and showing the calculation of them.

Precedence diagram of the assembly line is shown in Figure 5.5. We have 8 tasks. The tasks are shown as nodes. The operation times of the tasks are indicated in the nodes. There are 4 workstations. Tasks 1, 3 and 5 executed at Station 1; Tasks 6 executed at Station 2; Tasks 2 and 7 executed at Station 3; Tasks 4 and 8 are executed at Station 4. Cycle time of the assembly line ise 75 seconds.

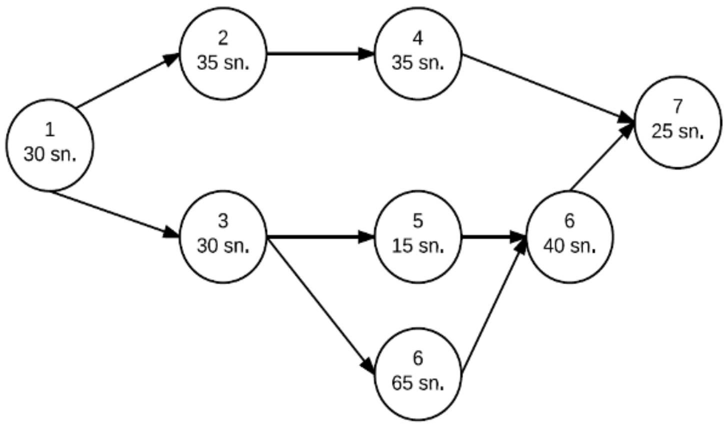


Figure 5.5 The precedence diagram of the example

Some OCRA parameters are constant because of the ideal condition of the working area. CF = 30, RcM = 0.6 and DuM = 1. Also, the repetitiveness multiplier has a constant value for our problem because technical actions of upper limbs are operated more than 50% of the cycle time for all tasks. So RM = 0.7 for the example. Here is the data of technical action value for all tasks, operation time, posture, average force value and additional risk factor.

Table 5.6 OCRA parametres of the example for the right upper limbs

Task No	Number of Technical Actions	Operation Time (sn)	Posture (PM)	Average Force Value(FM) (%)	Additional Risk Factors
1	10	30	Elbow flexion(≥60)	20	1
2	12	35	Hand Pinch	10	2
3	8	30	Wrist extension(≥45)	18	3
4	11	35	Wrist ulnar deviation(≥20)	10	4
5	6	15	Palmar grip	15	5
6	13	65	Hook grip	7	6
7	10	40	Elbow supination(≥60)	15	7

OCRA index must be calculated for both right and left side of the body seperately. Then, the higher OCRA index which has worse ergonomic conditions is selected. In our example we calculated only right hand OCRA index. The operation detail can be understanding from the posture explanation. To explain we only show the OCRA index calculation for Station 1 but the solution of the parametres for other stations are on the solution tables. To calculate OCRA index; we calculate Actual frequency first.

OCRA index = Actual frequency / Recommended frequency

Number of technical actions = 10 + 8 + 6 = 24

Station Time = 30 + 30 + 15 = 75

Actual frequency = 24 * 60 / 75

Table 5.7 Actual frequency and station time values for all stations

Station No	**Total Number of Technical Actions**	**Station Time**	**Actual Frequency**
1	24	75	19.2
2	13	65	12
3	22	75	17.6
4	16	60	16

Then to calculate Recommended frequency we have to *CF, PM, FM, RM, ARF and RcM, DuM* value. Wepreviously set *CF, RM, RcM* and *DuM* value 30, 0.7, 0.6 and 1, respectively.

For determining *PM,* the type of the awkward posture and its corresponding cycle time share are required. Task 1, 3 and 5 are executed at Station 1. We compute the cycle time share as follows.

Task Time / Station time * 100

For Task 1; cycle time percent is 30 / 75 * 100 = 40% where 75 is computed by the sum of operation times of task 1, 3 and 5 that are executed at Station 1 (30 + 30 + 15). For Task 1; the type of the awkward posture is Elbow flexion(≥60); the cycle time percent is 30 / 75 * 100 = 40%. So, PM is read as 1 from Table 5.6. For Task 3; the type of the awkward posture is Wrist extension(≥45); the cycle time percent is 30 / 75 * 100 = 40%. So, PM is read as 0,7 from Table 5.6. For Task 5; the type of the awkward posture is Palmar grip; the cycle time percent is 30 / 75 * 100 = 20%. So, PM is read as 1 from Table 5.6. We can find the posture value by this way. For Station 1; PM values are 1, 0.7, 1, respectively. The smallest value 0.7 is the PM value of the Station 1.

Table 5.8 The PM solution for all stations by task

Station No	PM Calc.	TASK NO								Station PM
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
1	**PM %**	**40**		**40**		**20**				0.7
	PM	1		0.7		1				
2	**PM %**						**100**			0.5
	PM						0.5			
3	**PM %**		**46.7**					**53.3**		0.6
	PM		0.7					0.6		
4	**PM %**				**58.3**				**41.7**	0.7
	PM				1				0.7	

To calculate the FM value, we must calculate the average force of the tasks which are belong to the Station 1. Here is the calculation for Task 1 for Station 1.

$$(30 / 75)*20 + (30 / 75)*18 + (15 / 75)*15 = 18.20 = \approx 18$$

By using interpolation method from Table 5.2 we can find the FM values.

$$0.85 - \{(0.85 - 0.65) / (20\text{-}10) * (18.20 - 10)\} = 0.69$$

Table 5.9 The force multiplier solutions for all stations

Station No	FM Calculation	TASK NO								Station FM
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
1	**FM**									18.20
2	**FM**									7.00
3	**FM**									12.67
4	**FM**									7.92

For other stations the solution can be found from Table 5.9. ARF multipliers are given in Table 5.6. We take the smallest ARF value from the tasks that are belong to the Station. So, the ARF value of Station 1 is 0.95. After the calculations we can find the OCRA index for Station 1.

Recommended frequency = CF * PM * FM * RM * ARF * (RcM *DuM)

Recommended frequency = 30 * 0.7 * 0.69 * 0.7 * 1 * (0.6 *1) = 6.1

Table 5.10 The solution of recommended frequency values for all stations

Station No	Total Number of Technical Actions	Station Time	Actual Frequency	CF	RM	RcM	DuM	PM
1	24	75	19.20	30	0.7	0.6	1	0.7
2	13	65	12.00	30	0.7	0.6	1	0.5
3	22	75	17.60	30	0.7	0.6	1	0.6
4	16	60	16.00	30	0.7	0.6	1	0.7

The recommended frequencies of all stations are shown in Table 5.10. We calculate the OCRA index work Station 1. We can find the OCRA index by using the parametres by the same way to calculate the other OCRA indexes. Table 5.11shows the results of the OCRA indexes for all stations.

OCRA index = Actual frequency / Recommended frequency

OCRA index = 19.2 / 6.1 = 3.2

Table 5.11 The OCRA index solutions for all stations

Station No	Operation	Station Time	Actual Frequency	Recommended Frequency	OCRA index
1	1, 3, 5	75	19.2	6.1	3.2 (Yellow)
2	6	65	12.0	5.3	2.3 (Yellow)
3	2, 7	75	17.6	5.7	3.1 (Yellow)
4	4, 8	60	16.0	7.2	2.2 (Green)

Red OCRA index means the ergonomic condition of the station is unacceptable. Yellow OCRA index means the ergonomic condition of the station is acceptable but under control. Station 1, 2 and 3 is Yellow. So working at this stations must be go on by under control. Green OCRA index means the ergonomic condition of the station is acceptable, working on the station is safe. Station 4 is Green, so working at this stations is acceptable.

5.4 The Importance of OCRA Index in the Industrial Application Method

OCRA index is an ergonomic risk assesment method which is especially used for analyzing upperlibs such as hand, wrist elbow and shoulder. It performs ergonomic analysis for each part of body separately (left and right). In other ergonomic risk assesment techniques the risk are not performs for each body body part. Also, OCRA index is appropriate for ergonomic analysis of repetetive tasks at high frequency. But in other techniques tasks are not considered according to repetitiveness.

These are the importance of the OCRA index for the industrial application method.

- The OCRA index is analysis each tasks of the work stations cumulatively. When the OCRA index is calculated if there are more than one task in a station, the OCRA index does not calculated separately for each station. A single OCRA index is calculated for all stations. Thus the cumulative impact of the tasks are taken into account.

- The OCRA index is not suitable for the production stages that has lots of lifting and carrying activities. It is more suitable for the working area which is based on a conveyor system. So the assembly line in the application is extremely appropriate in this context to examine.

- The OCRA index performs the upper body movements. Especially the upper body components such as elbow and shoulder are reviewed by OCRA index. The most frequent complaints of discomfort of the workers who works on the industrial application company are particularly hand and wrist discomfort.

Therefore the OCRA index that analysis the ergonomic risk factors of the repetitive tasks on the worker health effectively is selected for the industrial application method.

CHAPTER SIX
THE HEURISTIC METHOD OF ASSEMBLY LINE BALANCING PROBLEM

6.1 Introduction

Different solution methods are applied to assembly line balancing problem but one optimum solution has not been found. In this chapter, a rule based constructive randomized search algortihm is proposed. We sequence tasks and called it assignable task list by using 17 different task priority. We choose a subset of the assignable task lists by considering the cycle time limitation. It means the station is maximally loaded. Then ergonomic risk factors are added and the proposed rules of heurisitic is used to solve this unique problem.

The rest of the chapter is organized as follows. In section 6.2, the proposed rule based constructive randomized search heuristic is defined in detail. The flowchart of the whole problem is given. In section 6.3, the rule based task selection rules are defined. Then in section 6.4,according to these OCRA indexes a preemptive goal programming approach is explained. Because the problemis multi-objective, the preemptive goal programming gives us the best feasiblesolution by considering the predefined objectives. the rule based task selection rules are defined. Finally, in section 6.5 the context of this chapter is summarized.

6.2 The Proposed Rule Based Constructive Randomized Search Algorithm

In the ALBP literature, the main objective is generally to balance the workload between workstations smoothly, and only task times are taken into consideration when smoothing workload. However, the degree of difficulty of tasksis also very important. Two workers executing two different stations with the same station time are assumed to be equally loaded according to the traditional perception. In fact, even they have the same station time; their workloads are different because of the different tasks they execute, in real life assembly line configurations. In order to close this gap between the real life and the literature, we proposed an ALBP problem with considering ergonomic risk factors and balance workstations in an ergonomic manner by making ergonomic risk assessment.

The application of the Santez project includes whole three problems of the company that is explained in Chapter 7. So, we developed a rule based constructive randomized search heuristic for solving assembly line balancing and also worker assignment problem. The huge flowchart of the proposed heuristic for the ALWABP-2with considering ergonomic risk factorsis given in Figure6.1. This thesis flowchartare comprised only assembly line balancing on the main assembly line and OCRA index application.

The heuristic prioritize tasks and sequentially assign tasks to the current station. Assignable tasks are determined according to the precedence relations and the rule based search algorithm, which will be explained in detail in section 6.2.1, is applied. After prioritizing tasks, a task is chosen randomly via roulette Wheel selection. All assignable tasks are chosen one by one and are put in order sequentially. While choosing tasks from the sequential list sum of the operation times of the assigned tasks, namely station time can not exceed the cycle time.

In the end, if a feasible solution is obtained, then the current cycle time is reduced and the whole process is applied again. By this way, at every feasible iteration cycle time is diminished and finally one feasible solution with the minimum cycle time is gathered when maximum iteration number is achived.

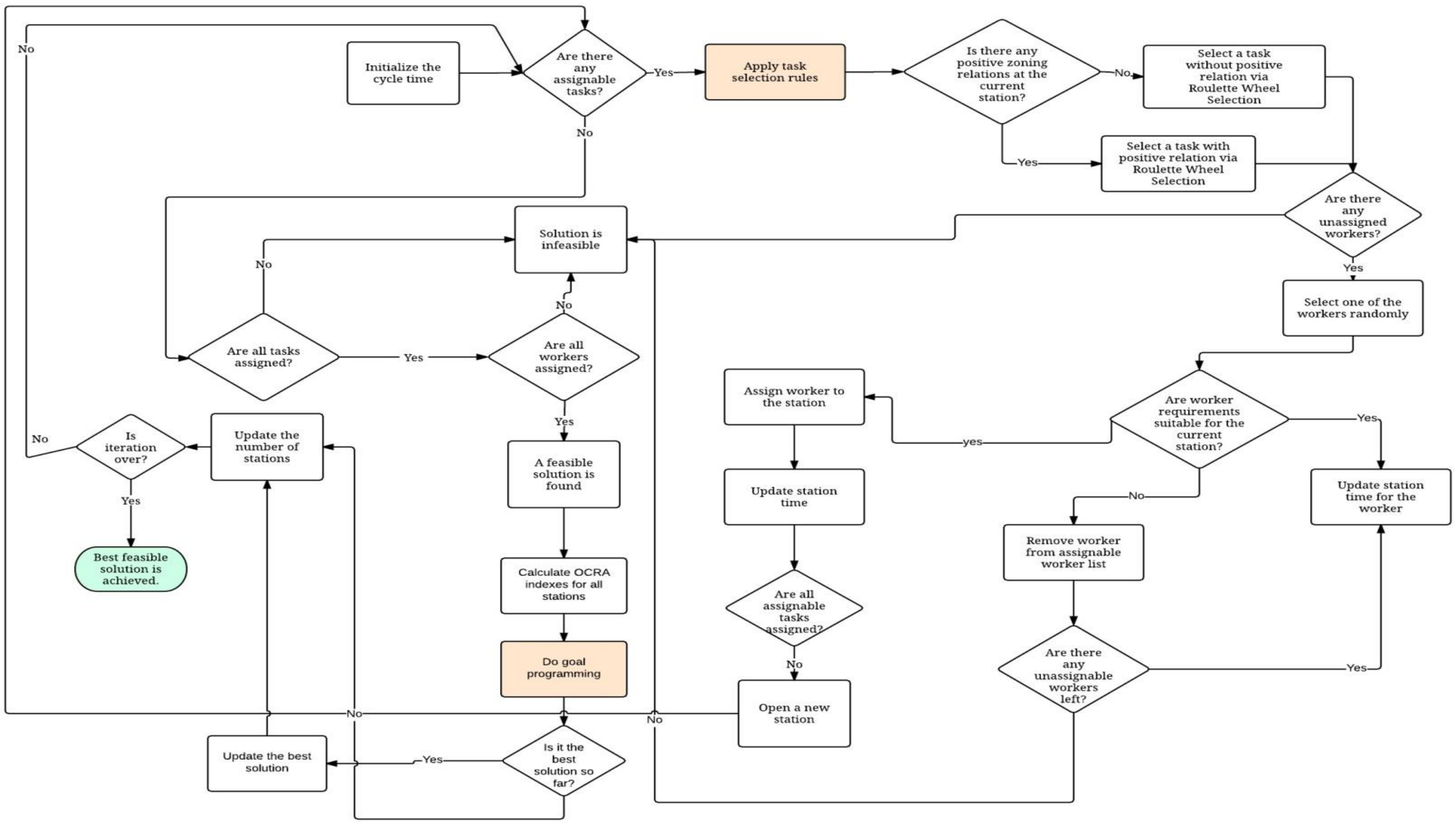


Figure 6.1 Flowchart of the proposed heuristic for the industrial application

6.3 Rule Based Task Selection Rules

Most of the above rules are inspired from Baykasoğlu (2006).Task priority rules used in the proposed heuristic is listed in the following:

1. Longest Processing Time (LPT),t_i
2. Shortest Processing Time (SPT),t_i
3. Greatest Number of Immediate Successors (GNIS), $|IS_i|$
4. Greatest Number of Successors (GNS),$|S_i|$
5. Random Priority (RND), random
6. Smallest Task Number (STN),i
7. Greatest Ranked Positional Weight (GRPW), $ti + \sum_{i \in si}^{i} t_j$
8. Greatest Average Ranked Positional Weight(GARPW),

   $(ti + \sum_{j \in si} t_j)/(|Si| + 1)$
9. Smallest Upper Bound (SUB)$N + 1 \left[(ti + \sum_{j \in Si} t_j)/C \right]^+$
10. Smallest (Upper Bound Divided by the Number of Successors) S_UB_NS $UB_i/(|S_i| + 1)$
11. Greatest (Processing Time Divided by the Upper Bound) G_PT_UB t_i/UB_i
12. Smallest Lower Bound SLB $\left[(ti + \sum_{j \in P_i} t_j)/C \right]^+$
13. Minimum Slack MSLK $UB_i - LB_i$
14. Minimum (Number of Successors Divided by Task Slack) M_NS_SLK $|Si|/(UBi - LBi)$
15. Greatest Number of Immediate Predecessors GNIP $|IP_i|$

16. Greatest Number of Predecessors (GNIP), $|P_i|$

17. Greatest Task Time Divided by Task Slack (TT_SLK) $|Si| / (\mathrm{UB}i - \mathrm{LB}i)$

The first rule is to select the task with the longest processing time. The second rule is just the opposite of the firstones. It seek for the task with the shortest processing time. Rules number 3 & 4 choose a task with the maximum number of immediate successors and successors, respectively. On the contrary, rules number 15 & 16 choose a task with the maximum number of immediate predecessors and predecessors, respectively. 5th rulerandomly prioritize a task. Rule number 12 prioritize a task with the minimum task number. Rule7 selects a task with the maximum ranked positionalweight. Similarly, rule 8 finds a task with the greatest average ranked positional weight. Rule 9 seeks for a task that has the smallest upper bound value. 10th rules seek for a task that with the smallest upperbound value divided by the number of successors. Similarly, rule11 looks for a task that has greatest processing time divided by the upper bound. Rule 12 prioritizes a task that has smallest lower bound. Rule 13 selects atask with the smallest slack value which is calculated by using upper and lowerbounds. 14th rule seeks for a task with the smallest number of successorsdivided by task slack. Finally, rule 17 prioritizes a task with the task timedivided by task slack value.

Assignable tasks are prioritized by using theserules. Higher selection probability. A task is randomly selected within assignable tasks.This strategy is called roulette wheel selection in the literature. The pseudo code ofthe proposed rule-based adaptive task search mechanism is illustrated in Figure 6.2.

```
procedure: Rule based adaptive task search method
input: assignable tasks, assignable workers
output: task to assign
BEGIN
    FOR each rule
        apply rule to assignable tasks
        add points to the appropriate task(s)
    ENDFOR
    create a task probability list
    FOR each task in assignable tasks
        give probability to task directly proportional to task points
        add task probability to task probability list
    ENDFOR
    Select randomly one task from the task probability list
END
```

Figure 6.2 Pseudo code of the proposed rule-based adaptive task search algorithm

The proposed algorithm makes use of the task assignment rules and tries tofind the smoothest assembly line with the minimum numberof workstations. The task assignment procedure of the developedalgorithm resembles the COMSOAL algorithm. However, it tries to find the best possible rule combinationin each task assignment.

6.4 Fitness Evaluation by Preemptive Goal Programming

There are many objectives in the proposed problem with ergonomicrisk factors, such as: minimizing cycle time, minimizing number of red stations, minimizing average red OCRA index, mean absolute deviation (mad) of all stations' OCRA indexes, average of all stations' OCRA indexes.

In this study, we solve classical ALBP with considering ergonomic risk factors. Since there is no relevant work in the literature that studying ergonomic conditions in

ALBP, we have no recent reference to compare our results.Hence, in order to make a meaningful comparison we develop a methodology. First,we solve the classical ALBP without taking into account any ergonomicconditions. Then, we solve the same test instance with considering ergonomic riskfactors. We evaluate new solution via preemptive goal programming approach. Wemake preferences among above mentioned objectives and put them in order. By thisorder of objectives, we decide the current feasible solution is the best one or not. Weinspired this methodology from Baykasoğlu (2006).

The pseudo code of the preemptive goal programming algorithm is given in Figure 6.3. Note that the primary objective is the number of red stations. If current solution has a smaller number of red stations than the best solution, then best solution is updated. In case of equality between two solutions, the secondary objectives are evaluated. The secondary objective is the average of red stations' OCRA indexes. If both of the primary and secondary objectives of the current solution are better than the best solution, or primary objectives are equal but current solution's secondary objective is better, then best solution is updated. Third and fourth objectives are mean absolute deviation (mad) of all stations' OCRA indexes (OCRAmad) andaverage of all stations' OCRA indexes, respectively. The whole procedure is same as the process that is explained for the first two objectives.

Mean absolute deviation of all stations' OCRA indexes is calculated as follows:

$$OCRA_{mad} = \sqrt{\frac{(OCRA_{avg} - OCRA_{station})^2}{\mathrm{K - 1}}} \tag{6.1}$$

where OCRA_{avg} and $\mathrm{OCRA}_{station}$ are the average of all stations' OCRA values and the OCRA value of the current station, respectively; and K refers to total number of workstations. The idea of setting OCRA_{mad} as third objective is to smooth workload between workers in terms of ergonomic risks. In classical assembly line literature, one of the most important performance criteria is smoothing the workload among the work stations as equal as possible. However, in such studies, only the operation times of tasks is considered to calculate workload. In other words, the assignment of workload to the workstations is based purely on task times and the degree of difficulty of tasks for workers is ignored. But, in real life assembly systems, unfavorable working conditions are also important and the control of ergonomic risk factors among workstations is vital. To overcome this gap, we propose OCRA$_{mad}$ as third objective.

```
procedure: Do goal programming (A3)
input: feasible solutions
output: best solution
BEGIN
    Create and initialize best solution object
    FOR each solution in feasible solutions
        Calculate OCRA average
        Calculate OCRA mad
        Calculate number of red stations
        Calculate average red OCRA index
        IF number of red stations < best solution's number of red stations THEN
            best solution = solution
        ELSE IF number of red stations = best solution's number of red stations THEN
            IF average red OCRA index < best solution's average red OCRA index
    THEN                    best solution = solution
            ELSE IF average red OCRA index = best solution's average red OCRA
                index THEN
                IF mad < best solution's mad THEN
                    best solution = solution
                ELSE IF mad = best solution's mad THEN
                    IF OCRA avg <= best solution's OCRA avg THEN
                        best solution = solution
                    END IF
                END IF
            END IF
        END IF
    ENDFOR
END
```

Figure 6.3 Pseudo code of the proposed preemptive goal programming algorithm

To clarify this process, we defined a function(F_i) that is given below. *i*isthe number of the function, Z_i the objectives of the problem.F_i: { Z_1, Z_2, Z_3, Z_4}

F_i= { The number of red stations, the mean absolute deviation, the number of red stations, the average of red stations' OCRA indexes}

Best feasible solution so far: Current feasible solution: Decision:

{7, 4.9, 1.9, 4.1} →	{5, 5.2, 2.0, 3.9} →	ACCEPT
{8, 5.8, 2.1, 4.8} →	{5, 5.6, 2.9, 3.4} →	ACCEPT
{4, 4.9, 1.4, 4.1} →	{4, 5.2, 1.6, 3.9} →	ACCEPT
{4, 3.9, 1.6, 2.9} →	{4, 3.9, 1.6, 2.5} →	ACCEPT
{3, 4.2, 2.3, 3.8} →	{3, 4.9, 2.1, 4.1} →	REJECT
{6, 3.8, 2.1, 3.2} →	{6, 3.8, 2.1, 3.3} →	REJECT

At first two examples, numbers of red stations are decreased in the current feasible solutions. So, there is no need to look into other objectives. We accept the current solution as the best solution. Example three illustrates that number of redstations are equal, but current solution's average of red stations' OCRA indexes valueis smaller than the best. Then, current solution is accepted. At example four, only thelast objective, average OCRA index value is smaller in current solution and the current solution is accepted. The last two examples are rejected. Example five illustrates the situation that the numbers of red OCRA stations are equal, but the current solution's average is greater. And in the last one, last objective value is higher in current solution. So, the best solution found so far is not updated in the last two examples.

CHAPTER SEVEN
THE INDUSTRIAL APPLICATION

7.1 Introduction

The aim of this chapter is to apply the proposed rule based constructive randomized search algorithm in order to solve an industrial case. The industrial case is presented at aharness production company which manufactures cable networks for automotive sector. The proposed problem is an over-constrained problem, so our rule based heuristic obtained satisfactory results for the company. The rest of this chapter is organized as follows. In section 7.2, the products and manufacturing environment of the company are presented. In section 7.3, the assembly line problem occurred at the company is defined in detail. In section 7.4, the proposed soltion method is applied to solve the well defined problem. Finally, in section 7.5 results of the industrial case implementationis defined.

7.2 Information of the Company

The company produces automobile cable network for auotomotive industry. It is a multinational company, whose origin is USA.It is first built in 1989 in Istanbul on a 9.800m^2 area. Then in 1992 another company is built in Bursa on a 13.400m^2 area, the last company is establishes in Izmir in 1997 with the bigest zone 20.200m^2. Production volume of the company is 10.687.235 hours/year with 72 assembly lines.

7.2.1 Overview of Production System

The harness production company has two main production areas; cable cutting area and final assembly area. In cable cutting area, cables are cut according to defined lenght using general assignment which is indepent from customer or product. After cutting operation, cut leads are distributed to related final assembly area to produce harness. The harness production system is defined in section 4.1 in detail.

7.3 Problem Definition

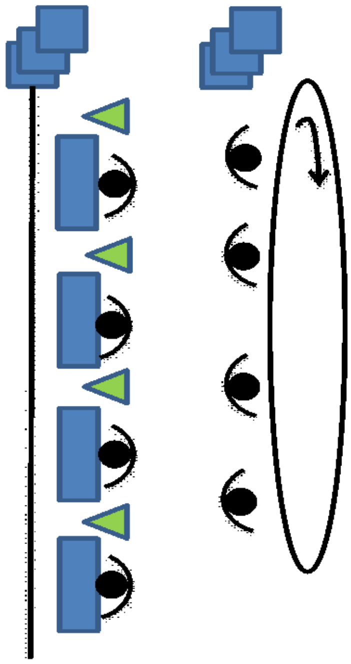
Assembly area contains subassembly, assembly, post prep and test area. During manufacturing system desing, operator assignment should be done by taking care of eliminating cross movements by station lay out and operational ergonomic constraints. Operator assignment to stations is done according to upper and lower level groups in accordance with defined constraints. As a consequence, during operator assignment to stations assigning similar work elements to station will provide assigning correct operator to the correct station.

Start up of new products, product design change or customer demand changes, drive new manufacturing system design or revision of present serial manufacturing design necessity. There is need for assign works to stations to assure productivity target by considering work priority alternatives, ergonomic factors and quality expectations in assembly area that has various models and variable demand. In present situtation, this process is done manually by methods engineers, by considering old experiences. Although all constraint and targets are considered it is difficult to find an optimum solution.

In this thesis we analzed the problem into three main problems.

- Main assembly line balancing
- Subassembly line balancing
- Layout problem of stations of the two assembly lines in order to minimize transactions between two lines.

The layout of the main and the sub-assembly lines are shown in Figure 7.1.The straight line is the subassembly linet hat feeds the main assembly line. Subassemblies that are manufactured in Figure 7.1 are transported to the main line in order to form the final product.



a) b)

Figure 7.1 The layout of the main and the sub-assembly lines. a) subassembly line b) main assembly line.

It is decided that manufactured a task at the subassembly or main assembly lines, in production planning phase. After assigning tasks to the lines, both of the lines are balanced. Note that, since the subassembly line feeds the main line both lines have the same cycle time values.

7.3.1 Balancing the Main Assembly Line

There are some problem specific constraints additional to traditional ALBP constraints, such as:

- Positive / negative zoning constraints: There are some zoning constraints due to the problem nature. When some of the tasks have to be operated on the same station, some of them have to be executed in separete stations because of worker and/or requirements.

- Ergonomic constraint: Because of the long working hours with working on the same posture and repetitive tasks many operators have musculoskeletal disesases especially at their hands and wrists. So, their ergonomic risk factors and the ergonomic analysis of the working space must be controlled.

- Operator height constraint: According to company policy, there are three categories for operator height, A is the operators whose height is between 1.5 and 1.6 meters. B is the operators whose height is between 1.6 and 1.7 meters. C is the operators whose height is greater than 1.7 meters.

- Transactions between subassembly stations: Although the main concept of the subassembly line is to feed the main line, there are some transactions within subassembly lines which cannot be avoided due to the problem nature. But, company management requested to minimize these transactions in order to eliminate cross movements.

- Assignment of the subaasembly line tasks constarint: The tasks that come from subassembly line is only one side of the main assebly line faces with the subassembly line. Tasks that are transmitted from subassembly line must be operated at the main assembly stations which are located on this side.

7.3.2 Balancing the Subassembly Line

Here is the constraint of balancing the subassembly line aditional to ALBP. In the balancing the main assembly line section we explain the constraints in detail.

- Positive / negative zoning constraints
- Ergonomic constraint
- Operator height constraint
- Transactions between subassembly stations

7.3.3 Layout Problem

This problem occurs due to the aim of minimizing total transactions between subassembly and main assembly lines and also within subassembly stations.

Layout problem is represented as Quadratic Assignment Problem (QAP) (Koopmans & Beckman, 1957), in the relevant literature. QAP basically assigns facilities to locations in order to minimize total transportation costs.

7.4 Proposed Solution Method

The real life problem that is defined is very complex and over constrained. So we seperate the problem into three parts. Thus, we solve whole problem the ALBP and layout problem separetely in the Santez Project in a PhD. This thesis subject is balancing the main assembly line.

7.4.1 Solution Procedure for the Main Assembly Line

There is not a situation that requires worker assignment in the proposed problem, because the only variable for workers is the operator height. The compnay management is assumed that task operation times are fixed and do not depend on the worker executing.

Moreover the concept of the problem is to design an assembly line for a new harness model production. It is understood taht we have to balance the line from the begining. There is no fixed number of workstations, and we know the cycle time of the line due to customer orders. Also, one homogeneous product is assembled in the line.

A typical SALBP-1notationis given in Table 7.1 as it is defined in section 2.2.

Table 7.1 Notation used in ALBP

i,r,s	Task
j	Workstation
C	Cycle time
$m_{\max}$	Maximum number of stations
n	Number of tasks
t_i	Operation time of task i
S	Set of precedence relations
x_{ij}	Binary variable equal to 1 only if task i is assigned to station j
z_j	Binary variable equal to 1 only if station $j$is opened.

The mathematical programming model for the SALBP-1 can be stated as follows (Scholl, 1999):

Min

$$\sum_{j=1}^{m_{\max}} z_j \tag{7.1}$$

Subject to

$$\sum_{j=1}^{m_{\max}} x_{ij} = 1 \qquad \forall i \tag{7.2}$$

$$\sum_{i=1}^{n} t_i \cdot x_{ij} \leq C.z_j \qquad \forall_j \tag{7.3}$$

$$\sum_{j=1}^{m_{\max}} j\left(x_{rj} - x_{sj}\right) \leq 0 \qquad \forall (r,s) \in S \tag{7.4}$$

$$x_{ij}, z_j \in \{0,1\} \tag{7.5}$$

i and j tasks, k workstation, K is the number of workstation, $\overline{K}$ the maximumnumber of Workstation that is determined before, V precedence relations diagram, FS_i is the set of potential workstations that the tasks(i) can be assigned. And x_{ik} is adecision variable that is 1 if task i is assigned to workstation k, if not the value of the variable is 0.

The objective function(7.1) refers to minimizing the number of workstations. The constraint (7.2) ensures that every task *i*is assigned to a single station *j*.

The inequation(7.3) provides to the station does not exceed the station time to the cycle time for all stations. The inequation(7.4) allows to control of the priorities. For doing such task *j* the i task should be completed. Any of job j came before it in order to do the job (s) should be finished. The last equation (7.5) indicates that i and kvariables are binary variables.

There are zoning constraints which is defined in the problem definition. We can add ZP_{ij} and ZN_{ij} are positive and negative zoning constraints, respectively. The constraint given in (7.6) states that tasks that have positive zoning have to be operated at the same workstation. The constraint given in (7.7) avoids executing incompatible tasks at the same station.

$$x_{ij} + M * (1 - (x_{ij} * ZP_{ij})) \geq 1 \tag{7.6}$$

$$x_{ij} - M * (1 - (x_{ij} * ZN_{ij})) \leq 0 \tag{7.7}$$

For ergonomic constraint solving we must show the OCRA index risks of the work place. One more constraint can be added to the model.

$$OCRA + d_i^- + d_i^+ = OCRA_{average} \tag{7.8}$$

The problem is over constrained and so complex that it is called NP-Hard. It can not be solved mathematical programming. We developed a proposed rule based constructive search algorithm in order to solve this problem. Also, we addepted the whole algortihm to a decision support system. The flowchart of the proposed heuritic is illustrated in Figure 6.1. In the flowchart at every iteration the number of workstations is updated.

The characteristics of the rule based task selection algorithm is explained in detail in Chapter 6. In order to simplify the process, we offer the company to label each task as its operation type. For this process, we use the following abbreviations as listed in Table 7.2.

Table 7.2Abbreviations of manufacturing operations

Assembly / plugging operations	A
Taping operation	T
Conduit operation	C
Tube operation	TP
Grommet operation	GR
Therostat operation	TR
Routing operation	ROT
Splice operation	SPL
Rolling operation	ROL
Kit hanging operation	HNG
Zuh operation	Z
Test operation	T

First the tas kare assigned to the stations according to the proposed rule based constructive search heuristic. Then the OCRA indexes of workstations must be computed to analyze the ergonomic risk level.

7.4.2 The usage of OCRA Index Parametres

In section 5.2 the Occupational Repetitive Actions (OCRA) Method is explainedin detail, in section 5.3 an illustrated example is given. Also, in section 5.4. The importance of OCRA index in the industrial application method is given. In this section the OCRA Index parametre of the industrial applicaton is given. So the usage of the OCRA parametres are stated better.

In order to simplify the process we classified the procedure to be used in programming and is given an acronym.

7.4.2.1 The Number of Technical Actions

We have to compute actual and recommended frequencies in order to calculateOCRA index. The computation of OCRA index is explained in detail in Section 4. Table 7.3 represents determination techniques of technical actions.

Table 7.3 Determinations of technical actions

Technical Operations	**Type of Operation**	**Number of Technical Actions**
Assembly / Plugging operations	Subassembly	3*number of assembled parts
	Mainassembly	2*number of assembled parts
PVC Taping operation	Discreate	3 + taping distance/(tape width + 2cm)
	Continous	4 + taping distance/(tape width + 2cm)
	Point	5 + taping distance/(tape width + 2cm)
Tenacious Taping operation	Discreate	4+taping distance /(tape width+2 cm)
	Continous	4+taping distance/(tape width)
	Point	5*number of point tapes
Sponge Taping operation	Continous	5+taping distance/(sponge width)
	Flag	5+(sponge lenght/80)
Linen Taping operation	Point	3*number of point tapes
Branch Taping operation	Point	6*number of point tapes
Conduit operation	Conduit	3+(conduit lenght/80)
Tube operation	Cut	2+(aks /80)
	Uncut	7*number of tube
	Uncut manuel	3+(tube lenght/80)
Grommet operation	Device	6+2*number of cables
	Manuel	3+2*number of cables

Table 7.3 Determinations of technical actions (continue)

Therostat operation	Therostat	6* number of therostat
Routing operation	routing	2*number of connector
	Cable routing	2*number of cables
Splice operation	With taping	10+number of cables
	With heatig	11+number of cables
	At the line	12+number of cables
Rolling operation	Long cable (>3m)	6
	Medium cable (1.5- 3m)	4
	Short cable (<1.5m)	3
Kit hanging operation	Kit	4
Zuh operation	Zuh	number of zuhes*6
Test operation	Test	6

By using the calculation method that showed in Table 7.3 we compute the number of technical actions and consequently, we find the actual frequency.

7.4.2.2 Posture Multiplier

We must set OCRA parameters to calculate recommended frequency. And actual frequency as it is stated in equation 5.11. Since *CF, RcM* and *DuM* are fixed multipliers, we have to determine *PM, FM, RM* and *ARF*. The classification of the posture multiplier parameter depending on the operations are listed in Table 7.4.

Table 7.4 The classification of the posture multiplier parameter depending on the operation

Operation	**Awkward Posture**	**Severe**	**Mild**
Assembly / Plugging operations	Hand pinch	X	
Taping operation	Wrist extension(≥45)	X	
Conduit	Elbow supination(≥60)	X	
Tube operation	Elbow supination(≥60)	X	
Grommet operation	Wrist flexion(≥45)	X	
Therostat operation	Power grip		X

Table 7.4 The classification of the posture multiplier parameter depending on the operation (continue)

Routing operation	Elbow supination(≥60)	X	
Splice operation	Power grip		X
Rolling operation	Elbow supination(≥60)	X	
Kit hanging operation	Hook grip	X	
Zuh operation	Hand pinch	X	
Test operation	Hand pinch	X	

7.4.2.3 Force Multiplier

Strain levels of the operations are given in Table 7.5 according to the cycle time of percent of the operation, the posture multiplier (PM) is set from Table 7.4.Average force level of the station is calculated by using Table 7.5 for indicated the force multiplier (*FM*). Then by making interpolation fromTable 5.2, FM parameter is found just as explained in numeric example in section 5.3.

Table 7.5The classification of the force multiplier parameter depending on the operation

Operation	**very, very week**	**Very week**	**week**	**moderate**	**somewhat strong**	**Strong / very strong**
Assembly / Plugging operations	X					
Taping operation	X					
Conduit		X				
Tube operation		X				
Grommet operation			X			
Therostat operation	X					
Routing operation	X					
Splice operation	X					

Table 7.5The classification of the force multiplier parameter depending on the operation (continue)

Rolling operation		X				
Kit hanging operation		X				
Zuh operation		X				
Test operation		X				

7.4.2.4 Additional Risk Factor (ARF)

Additional risk factors are given in Table 7.6. Bu using the following table and cycle time shares of operations *ARF* multiplier is determined.

Table 7.6The classification of ARF parameter depending on the operation

Operation	**Additional Risk Factors**
Assembly / Plugging operations	Using protective equipment - gloves
Taping operation	Using sharp equipment - scissors
Conduit	Using protective equipment - gloves
Tube operation	Using protective equipment - gloves
Grommet operation	Using sharp equipment -cutter
Therostat operation	Exposure to chemicals
Routing operation	Requirement for absolute accuracy
Splice operation	Using protective equipment - gloves
Rolling operation	-
Kit hanging operation	-
Zuh operation	Using dangerous equipment
Test operation	-

After stating all parametres of OCRA index with partners from the company, the risk levels of stations are computed by the decision support computer program.

7.4.3 The Decision Support System

We developed a computer program to solve the problem variation andapplied the proposed computer program to find out different solutions by using the rule based constructive randomized search heuristic. The program runs and gives solution in seconds, on the contrary of the manuel solving method of the method engineers. So time saving is another advantage of the computer program. These are the reasons of why a computer program is developed and used while solving the harness assembly line balancing problem and applied ergonomic risk assesment.

First of all we should run the set up exe to use the program. Figure 7.2 shows the steps of setup.

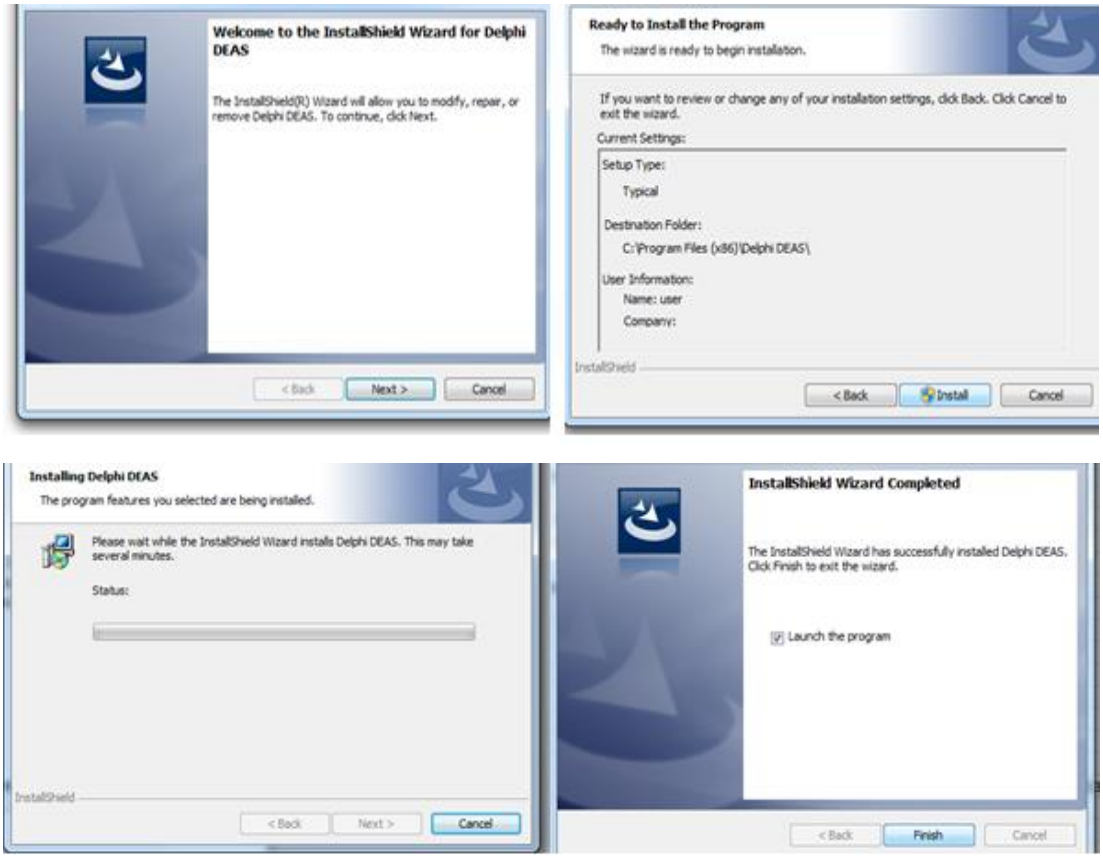


Figure 7.2 The setup of the computer program

The Figure 7.3 shows the user interface of the problemthat has an easy menu and directs the user to run the required data files.

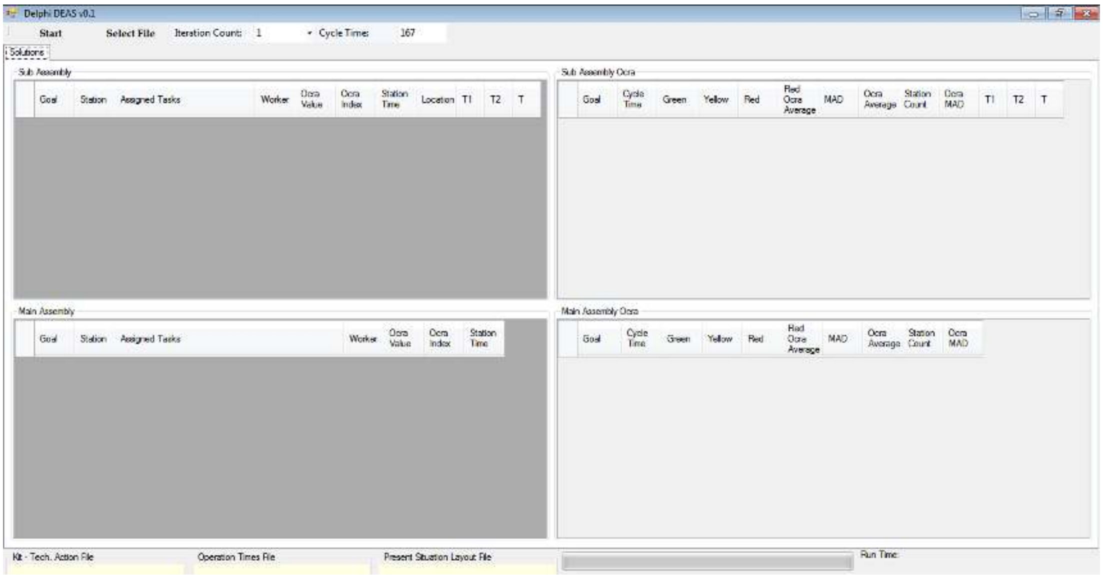


Figure 7.3 The user interface of the program

In the tool bar in Figure 7.4 depicts the required data files to run the program. Kit – Tech. "Action File" has data that shows the operation types, precedence between tasks and operator height. We should select the data file to use. Then select the Excel file that has operation times to run the system. If you want to make a solution that will has layout, you should select a present situation layout file, too. But in this study we do not interested in the layout solution because we do not analysis the sub and min assembly and transactions between them.

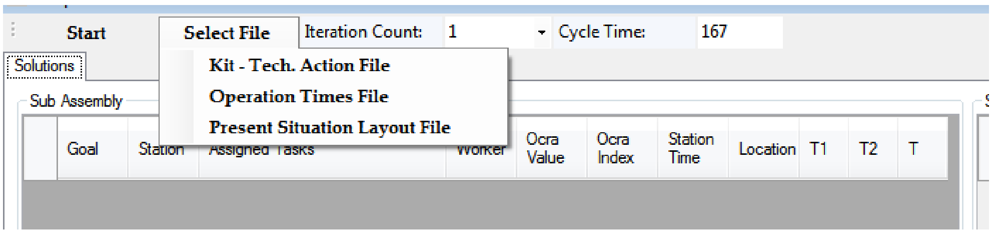


Figure 7.4 The menu bar of the program

In Figure 7.5 the menu bar shows the required data files to run the program. Kit – Tech. Action File has data that shows the operation types, precedence between tasks and operator skills.

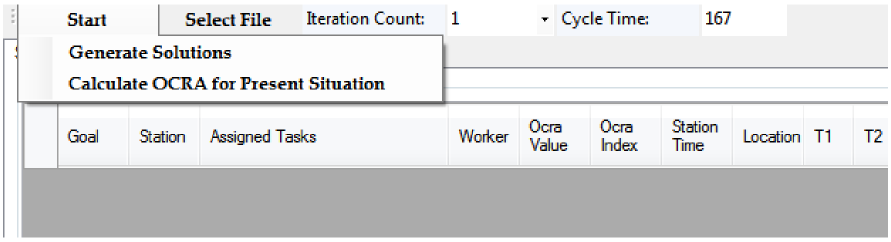


Figure 7.5 The starting section of the menu bar of the program

In the start section the user can be calculated the OCRA index for the present situation. Generating solutions are very easy understanding with the user friendly menu bar.

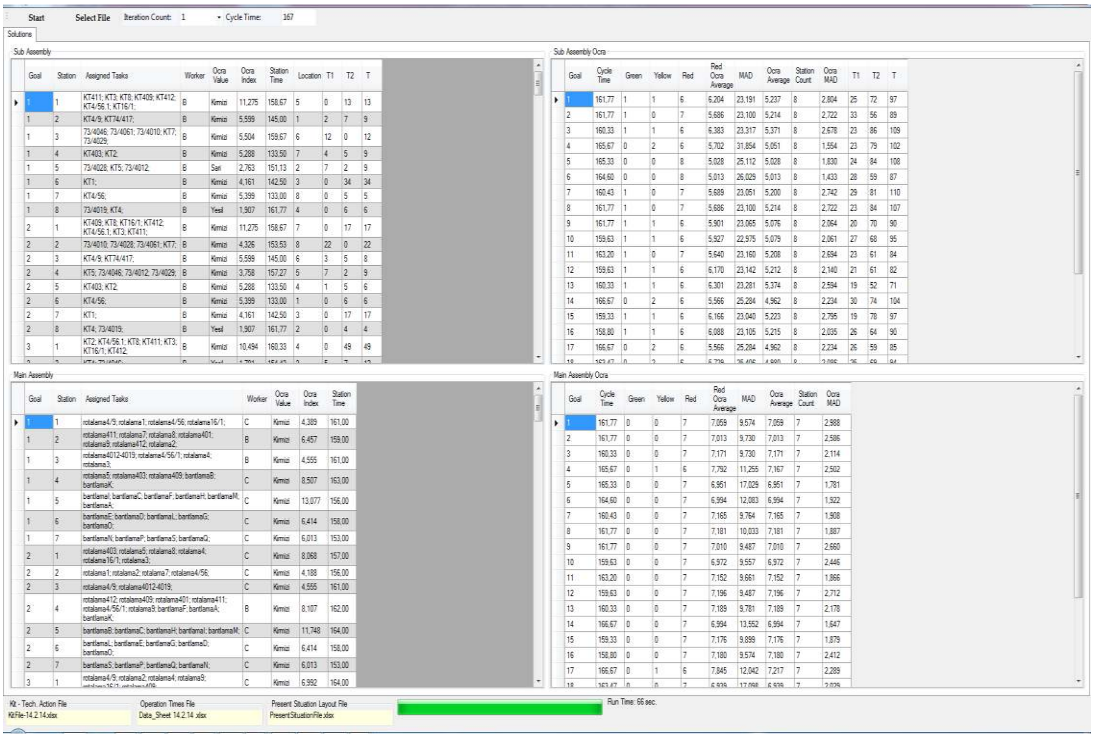


Figure 7.6 The result of the computer program

7.5 Results of the Industrial Case Implementation

First of all, we analyze the present situation of the company. There are task types, operator type, OCRA index value and the name of the line. We evaluate the ergonomic risk levels by using OCRA index.

Present situation of the working environment of whole problem of the harness assembly system that is studied on the Santez Project is illustrated in Figure 7.7. Also, the current status of the main assembly line is illustrated in Figure 7.8. There are 7 main assembly stations. Station numbers are written at the top of the each station (P1, P2…etc). The cycle times, the type of tasks and the OCRA index values are shown on the Figure 7.8. Station times and OCRA indexes are stated at the bottom of each station. All of the OCRA indexes are in the red zone.

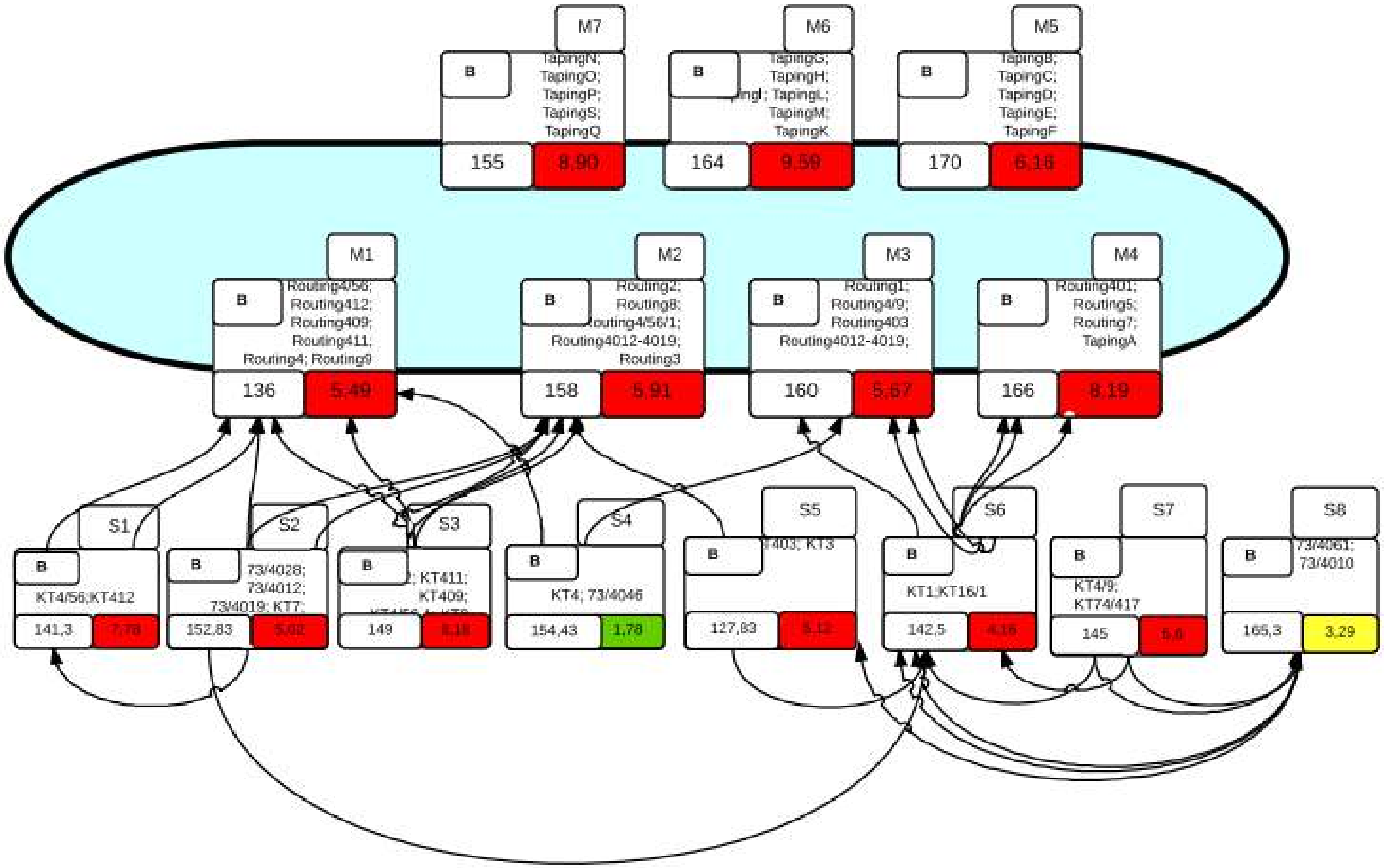


Figure 7.7Present situation of the working environment of whole problem of the harness assembly system

Table 7.7 Results of the industrial application

					Nr of stations	Cycle time(sec)	CPU time (sec)	Nr of green stations	Nr of yellow stations	Nr of red stations	Red Station Avg OCRA Index	MAD	OCRA Avg	OCRA MAD
	Present situation				7	165.30		0	0	7	7.13	14.46	7.13	1.71
1	G1,	G2,	G3,	G4	7	159.10	5.41	0	0	7	7.17	10.07	7.17	2.20
2	G1,	G2,	G4,	G3	7	161.77	4.54	0	0	7	7.17	10.25	7.17	2.28
3	G1,	G3,	G2,	G4	7	163.47	5.71	0	1	6	7.80	16.72	7.17	2.13
4	G1,	G3,	G4,	G2	7	166.17	4.84	0	0	7	6.79	17.13	6.79	1.62
5	G1,	G4,	G2,	G3	7	165.43	2.34	0	0	7	6.97	14.12	6.97	2.53
6	G1,	G4,	G3,	G2	7	161.00	4.43	0	0	7	6.93	17.09	6.93	2.15
7	G2,	G1,	G3,	G4	7	162.60	2.46	0	0	7	7.13	10.28	7.13	1.90
8	G2,	G1,	G4,	G3	7	162.83	2.62	0	0	7	7.16	9.78	7.16	1.84
9	G2,	G3,	G1,	G4	7	164.20	3.14	0	0	7	7.15	9.80	7.15	1.44
10	G2,	G3,	G4,	G1	7	166.77	2.69	0	0	7	7.15	9.92	7.15	1.20
11	G2,	G4,	G1,	G3	7	166.77	3.53	0	0	7	7.17	10.03	7.17	2.48
12	G2,	G4,	G3,	G1	7	165.60	3.62	0	0	7	7.17	9.97	7.17	2.66
13	G3,	G1,	G2,	G4	7	162.60	2.92	0	0	7	7.16	9.88	7.05	1.47
14	G3,	G1,	G4,	G2	7	165.30	1.32	0	0	7	6.97	13.67	6.97	1.61
15	G3,	G2,	G1,	G4	7	163.80	0.53	0	0	7	7.18	9.76	7.18	2.04
16	G3,	G2,	G4,	G1	7	163.00	4.09	0	0	7	7.01	10.20	7.01	2.18
17	G3,	G4,	G1,	G2	7	165.30	2.62	0	1	6	7.79	11.79	7.17	2.15
18	G3,	G4,	G2,	G1	7	166.77	0.96	0	1	6	7.65	12.49	7.05	2.32
19	G4,	G1,	G2,	G3	8	163.80	0.85	0	0	8	6.71	49.61	6.71	2.22
20	G4,	G1,	G3,	G2	8	165.43	1.94	0	0	8	6.81	49.14	6.81	2.20
21	G4,	G2,	G1,	G3	8	165.60	2.21	0	0	8	6.75	49.00	6.75	2.69
22	G4,	G2,	G3,	G1	8	164.60	4.16	0	0	8	6.66	49.00	6.66	2.72
23	G4,	G3,	G1,	G2	7	164.00	1.90	0	0	7	6.90	17.12	6.90	2.55
24	G4,	G3,	G3,	G1	8	166.76	1.3	0	0	8	6.69	49.24	6.69	2.48

We analyze the problem to achieve the 4 goals which arestated in section 6.4.

- minimizing number of red stations,
- minimizing average red OCRA index,
- mean absolute deviation (mad) of all stations' OCRA indexes,
- average of all stations' OCRA indexes.

This problem is solved by the proposedheuristic method that is written in C # by using Visual Studio program.It is verified by an i7 processor computer at 1000 iterations. While analyzing the all 4 goals, we obtain 24 (4!) different solutions with different goal sequences. Because we change the ranking of the goals, then solve the problem. The results are reported in Table 7.7.

First column represents the number of solution. Second states the goal sequences. Analysis of the present situation is reported, then obtained solutions are listed. G1, G2, G3 and G4 are the goals, which is stated previous sections; minimizing number of red stations, minimizing average red OCRA index,mean absolute deviation (mad) of all stations' OCRA indexes,average of all stations' OCRA indexes, respectively.

For the first solution, minimizing the number of red stations (G1) is the pirmary goal and average of all stations' OCRA indexes (G4) is the last one.

As it seen from the Table 7.7total number of stations, cycle time, number of green stations, number of yellow stations, number of red stations, average red OCRA index, mean absolute deviation, average OCRA index of all stations, and mean deviation of OCRA indexes are given.

Finally we find 24 different solutions. One of the 24 solutions is selected to be implemented at manufacturing area. Due to theresults ergonomic conditions of the workspace are poor. In order to reduce the risk level of the OCRA index solution some actions must be taken by the company, immediately. Solution number 1 is selected to be implemented at the manufacturing plant of the company. The solution of the implementation is illustrated in Figure 7.8.

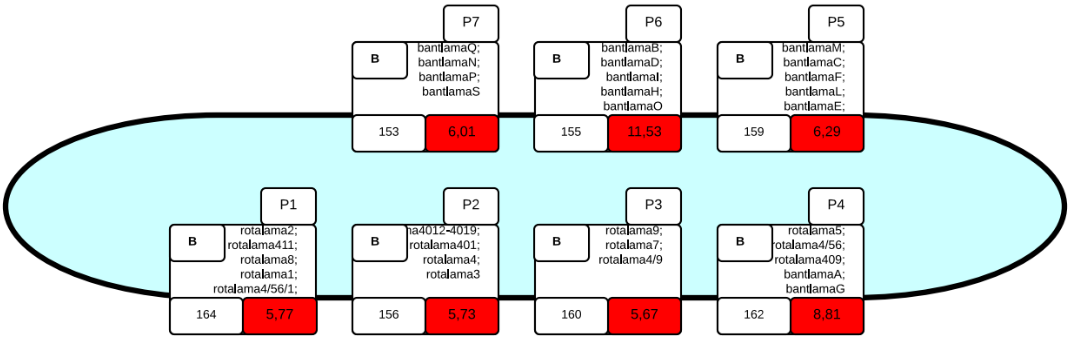


Figure 7.8 The implementation of the solution 1

The results show that, by using the proposed preemptive goal programmingapproach we generate solutions with better ergonomic conditions.

We decrease number of red stations and average value of all stations'OCRA indexes while increasing number of yellow stations that means improving the ergonomic environment ofthe assembly line. Note that the motivation of the ALBP isto employ disabled workers, this is very important. Ergonomic conditionsof the working environment is important for human health, but it is vitalessential for disabled workers.

To compare the present situation of the assembly line and the implementation of the solution 1 which is developted by using the proposed heuristic, achivied lots of gain.

- In present situation the problem is solving by the industrial engineers of the company manually. By using the decision support system it can be solved by a systematic computer program.

- The problem solving takes about 8 weeks. By using the proposed solution method it takes only few seconds. The company provides time saving.

- The engineers have to considers various constraints at the same time, simultaneously. By using the proposed decision support system all of the constraints are defined and categorized. It provides fault elimination.

- While problem solving the engineers not consider the ergonomic risks of the assembly line working environment. Now by using the OCRA method ergonomic risk can be evaluated, and it is a solution of the proposed heuristic.

- Although we decrease the number of red stations dramatically, we couldn't eliminate all of them. It may be required to hire one more worker and open a new station to get rid of all red stations.

- In order to improve ergonomic conditions, we have to increase cycle time a little bit. So, break-even analysis must be done and the decision of improving ergonomic conditions or not must be made by evaluating financial factors.

Finally, we applied the proposed computer program and find out 24 different solutions with regard to different sequences of goals. One of the 24 solutions is selected by the company to be implemented at the manufacturing area. The results showed the poor ergonomic conditions must be taken into consideration.

In the end of this Santez project, we developed heuristic and it is implemented successfully by the company.

CHAPTER EIGHT
CONCLUSION

8.1 Summary

Under the conditions of tough competition, the importance of an efficient production system is increased. The way to reduce the production costs and respond to the customer demand in time is passed from the standard production system in assembly lines. However, in classical assembly line balancing literature, all workers are assumed to be same skills, ergonomic conditions are not taken into considerition. But human factors play an important role in labor intensive assembly lines. Today, companies that embrace ergonomics expect a safe work environment as well as an increase in efficiency and productivity. It is the goal of ergonomics and human factors engineering to achieve an optimal fit between work requirements and operator capabilities.

Assembly line balancing problem (ALBP) is introduced with condering human factors. By using the OCRA method ergonomic risk factors is applied to the real life problem.

In this thesis, to deal with the ALBP rule based constructive randomized search algorithm search heuristic is proposed.

There is only a few research on the OCRA method in literature. ALBP that considers ergonomic risks is introduced. OCRA index is used for ergonomic risk assesment. In order to deal with the multi-objective problem, a preemtive goal programming approach is used.

A new constructive heuristic is developed to solve ALBP. Ergonomic risk assesment is introduced in ALBP. There is not any study in the current literature that considers ergonomic factors in ALBP. In order to solve this over constraint problem the proposed rule based constructive randomized search heuristic is used.

Also the proposed heuristic is applied on a manufacturingplant that produces harness. The company management is imformed about ergonomic risks about the working environment. They decided to consider of the ergonomic risks and take actions in order to reduce the risk. Also the time that is used for line balancing is decreased from 8 weeks to seconds.

8.2 Future Research Directions

The application of the developed model requires an adaptation to the real industrial situations, which could be the base for some future researches.

Ergonomic risk factors are considered as the constraints in this thesis. It can be used as a part of the objective function in other studies.

The proposed heuristic is applied on a real harness production assembly line. The heuristic can be extended to solve different type of assembly lines with a different line balancing problems.

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